WHY ARE MAGNI GYROS SO STABLE?

There are many viewpoints in the gyroplane world as to what goes into making a gyroplane stable. There are many viewpoints as to whether this is even an important parameter. The viewpoint I am presenting here is my view and just one viewpoint.

Gyroplane stability refers to a number of issues. How easy is it to fly or to learn to fly? How well does it handle wind turbulence? Of particular importance is how resistant is it to Pilot Induced Oscillations (PIO) and/or a "bunt-over" - often called a Power Push-Over (PPO). All aircraft have varying degrees of stability as a result of their aerodynamic configuration. But, gyroplanes have particular issues because the "wing" of the gyroplane - the rotor - is not "fixed" to the airframe. In an airplane, the wing is fixed to the airframe, thus they are referred to as "fixed wing". The fact that the rotor in a gyroplane is not fixed to the airframe directly, but is controlled through cyclic action of the control system, makes gyroplane stability issues much more difficult and important. And, this fact makes the erroneous application of fixed-wing analogies particularly mis-leading.

Maneuverability vs. Stability:

One gyroplane property that people often associate with stability is maneuverability. A traditional fixed-wing analogy, inaccurately applied to gyroplanes, is a concern that if a gyroplane is very stable it will not be maneuverable - AKA, fun to fly! The flight path, or change in flight path, speed and direction, of any aircraft is the result of a change of attitude of the lifting element - wing or rotor -- not of the airframe. Because gyroplanes are not "fixed wing" aircraft, the lifting element - the rotor - is controlled independently by pilot input and does not depend on control surfaces to move the airframe to cause a change in the lifting element. And, because the rotor disk is moved or changed by a very powerful and responsive cyclic action, the rotor can be made to change attitude much more quickly and with much more authority than can a wing, which is attached to a high inertia airframe.

The gyroplane actually has the best of both worlds of this stability / maneuverability relationship. A stable gyroplane is one that actually has a stable airframe. An unstable gyroplane is one that has an unstable airframe. A stable gyroplane airframe is one that follows or accurately tracks the flight path - in other words, the rotor determines the flight path and the airframe follows or tracks like an arrow on that flight path.

Having said that the gyroplane rotor is not "fixed" to the airframe and that the airframe does not have to change attitude in order for the rotor to change attitude, the airframe attitude does have a part to play with the rotor attitude. However, the pilot is the interface between the airframe and the rotor. That means, without pilot input, through either control system friction or trim input, or pilot holding the control stick steady ("fixed"), the rotor WILL follow the airframe attitude - the same as a "fixed wing". This is actually what causes the "stability" of a gyroplane with a stable airframe - without pilot input, the stable gyroplane airframe will force the rotor to follow the airframe attitude. However, with pilot commanded cyclic input added to the airframe uncommanded cyclic input, the pilot can cause the rotor attitude to change much faster than the airframe would otherwise allow it, and therefore very powerfully adjust the flight path of the whole aircraft. In this case, the stable gyroplane airframe will be aerodynamically forced to follow the flight path dictated by the lifting element - the rotor.

Another quality of maneuverability is how precisely the pilot is able to control the aircraft in the desired maneuver - change in flight path or airspeed. The pilot controls that maneuver through commanded cyclic rotor control inputs. The pilot requires a reference from which to sense the progression of any maneuver and precisely provide further commanded maneuvering inputs - airframe attitude feedback. In a stable gyroplane, one where the pilot's reference - the pilot's seat and the airframe visual attitude reference relative to the horizon - accurately represents the actual maneuver of the aircraft. This is because the airframe attitude accurately tracks the flight path. In this case, the pilot has an accurate reference from which to make compensating or appropriate cyclic inputs. In an unstable gyroplane airframe, the airframe attitude does not track the flight path and requires extensive familiarity and experience with that gyroplane in order that the pilot may interpret the attitude responses of the airframe and provide accurate commanded cyclic rotor inputs to precisely control the maneuver. The definition of true maneuverability is both the ability of the aircraft to change flight path and airspeed, and the precision with which the pilot is able to control that maneuver. What is often interpreted on unstable gyroplanes as "maneuverability" is the perceived erratic response of the airframe when it fails to track either pitch or roll attitude relative to the flight path.

The bottom line on the maneuverability issue is, a stable gyroplane, no matter how stable the airframe, is equally as maneuverable as an equivalently sized unstable gyroplane. One thing that does affect gyroplane maneuverability - equally in stable and unstable gyroplanes - is the overall weight of the gyroplane. The inertia of the whole aircraft makes a heavy gyroplane a bit less maneuverable than a relatively light gyroplane. However, the rotor would be sized proportional to the weight of any gyroplane. The rotor power to change the flight path (rotor power is very powerful and responsive compared to a wing - elevator/aileron system), even for heavy gyroplane, is very impressive, relative to a light gyroplane. Because a light gyroplane can therefore be a bit more maneuverable, it is therefore even more important that that gyroplane be stable and forgiving and self-correcting to uncommanded maneuver inputs.

A Stable Airframe:

Although the aerodynamic design and properties of a rotor can affect the degree of stability of a gyroplane, the major element affecting a gyroplane's overall stability is the stability of the airframe. This airframe stability can be defined according to two variable factors:

- How accurately and rapidly does the airframe attitude aerodynamically respond to a change in relative wind? Relative wind can change from either wind turbulence or from pilot commanded cyclic input that changes the flight path or speed of the gyroplane.

- How rapidly and in what direction does the airframe attitude respond to changes in rotor lift - or g load on the aircraft.

The aerodynamic stability of the airframe is somewhat intuitive. Essentially, the more it reflects the qualities of an arrow, the more the airframe attitude will track and respond to the relative wind. This quality includes the size and aerodynamic efficiency of the tail surfaces - vertical and horizontal stabilizers - relative to the airframe aerodynamic properties, lift and drag, forward of the CG. Essentially, the aft stabilizing surface volumes (area of the stabilizer times it's moment arm from the airframe CG) must be larger than the surface volumes forward of the CG - the larger the better. The Magni Gyroplane has extremely large and effective vertical and horizontal stabilizers. They employ efficient airfoil shapes and are located far aft of the aircraft's CG - long moment arm and essentially high tail volume. In addition to the airfoil shapes, the arrangement of vertical tip rudders on the horizontal stabilizer improves the effective area of both the horizontal and vertical stabilizing action. And the rest of the fuselage is designed for low drag and a constant and controlled center of pressure (Center of Drag) to maintain balance with the stabilizers and the rest of the moments acting on the airframe. Just looking at the Magni, it's easy to see the attention to aerodynamic cleanliness, from the large tail surfaces, to the low drag enclosure, landing gear and wheel pants.

Airframe response to g load is another important stability factor. Essentially, like any aircraft, the lift vector of the rotor (lifting element) must be aft of the CG. When this is the case, on any aircraft, a g load transient will cause the airframe to move in the direction to reduce that g load. This is the essential element of stability on any aircraft. On a "fixed wing" airplane, the loading limits established by the designer assure that the CG is forward of the lift vector of the wing. The aircraft designer specifies the aircraft loading so that the CG is properly forward of the lift vector to achieve the desired stability for that aircraft.

For a gyroplane, it is a different story. The rotor is not "fixed" and so the rotor lift vector and CG are able to move relative to each other. And, there are a number of "moments" acting on the airframe so as to cause the CG to move relative to the lift vector - possibly reducing the stability or even causing negative stability if the CG is forced aft too far - from nose-down moments on the airframe. Alternatively, if the CG can, through the balance of static moments on the airframe, be caused to be remain well forward of the rotor lift vector, the essential g-load stability will be enhanced.

The "moments" acting on the airframe to position the CG relative to the rotor lift vector are several. First, the rotor lift vector is, hopefully trying to rotate the nose lower - analogous to the wing lift vector on a properly balanced airplane trying to rotate the nose lower. Then there is the effect of the propeller pushing - possibly not directly aligned with the CG of the gyroplane for that particular flight. The CG may be different for different weight pilots or passengers, for different fuel, or possibly for baggage squirreled away somewhere on the gyro. Whether the prop thrustline is above or below the CG, causing a nose down or nose up moment, depends on the configuration of the gyroplane and possibly on the loading of the gyroplane on that particular flight. Then, there are moments from the rest of the airframe, fuselage, windscreen(s), landing gear, etc. possibly trying to force the nose up or down. And finally, hopefully, there is a large balancing moment from a horizontal stabilizer. The horizontal stabilizer must "balance" all of these other moments, under all conditions of load, power and airspeed, to keep the airframe level to the airstream and the CG properly forward of the rotor lift vector.

This g-load stability factor is essential because any transient and any pilot commanded pitch input will present g loads on the aircraft - and it is essential that the airframe pitch in the direction to reduce the effects of this g load transient. The aircraft should pitch in the direction to restore the g load back to one "gravity". If a g load acts to pitch the airframe in the direction that increases that g load change, the whole system is possibly "divergent" and is either very difficult or impossible for the pilot to stabilize. This would be somewhat akin to balancing a ruler on your finger - negative stability.

A gyroplane who's fuselage pitches in the correcting direction for a g-load transient, will tend to restore the gyroplane back to one gravity load. This would be akin to hanging a ruler on one end from your fingers - positive stability. (Neutral stability, which in a gyroplane would be quite squirrelly, is akin to balancing a ruler on a nail at the 6 inch point).

The Magni gyroplanes are aerodynamically balanced to maintain the airframe essentially level to the flight path - which positions the CG well forward of the rotor lift vector. The fuselage and other airframe moments are minimized and controlled so they can be properly balanced with the horizontal stabilizer moment and the other moments on the airframe.

There are other stabilizing factors to work in conjunction with the stabilized airframe:

Rotor / Airframe harmony:

The airframe and rotor both have inertia with forces and moments acting on them to cause movements against that inertia. All such physical systems with inertia and forces and moments, will have a natural frequency of oscillation. This means they may tend to oscillate in reaction to a disturbance - turbulence or pilot input. If the system is DYNAMICALLY stable, the oscillatory response to a transient will cause the transient to diminish or decay back to steady state. If the system is dynamically unstable, the oscillations will increase in amplitude - divergent. The goal of any control system, including an aircraft, is to be "damped" to such a degree that the oscillations quickly decay to zero.

When two or more components of a system, each having their own natural frequencies of oscillation and inertia, act on each other (as a rotor and airframe will do), the way these frequencies act together can be either "harmonious" or non- harmonious. (Think of the different strings on a guitar!). In a control system such as a gyroplane, the goal is to harmonize the natural reactions of these components so that they tend to act to reduce the effect of each other DYNAMICALLY. This means for instance that the inertial reaction of the rotor does not "feed" or resonate with the oscillations of the airframe so as to worsen or excite worse oscillations in the airframe, and vice-versa. The Magni rotor and rotor system is designed to act DYNAMICALLY in harmony with the airframe inertia and control system. In actuality, this is the major reason the Magni stands out in stability feel among all other gyros. Magni has achieved this result through careful and professional aeroDYNAMIC design, and lots of trial and error design iteration and flight testing.

Control Friction:

For an unstable - airframe that responds to disturbances in the wrong, or destabilizing direction - it is extremely important that the pilot and/or the control system does not allow those airframe motions to couple into the rotor. If they do so, the rotor - lifting element - will cause that initiating disturbance to be increased - "positive feedback". Most gyroplanes will couple some amount of airframe motion into the rotor from control friction and most certainly from the trim spring / offset gimble arrangement on the rotor head. This means, that for an unstable airframe, the pilot must COMMAND precisely timed compensating inputs into the rotor so that the rotor does not "feed" the errant reactions of the airframe and cause the whole gyroplane system to diverge in either pitch or pitch oscillations.

A gyroplane airframe that is stable and responds the proper direction to wind turbulence or g load disturbances cannot, by itself alone, cause the flight path of the whole gyroplane to move or pitch in a correcting direction. For a gyroplane, who's stable airframe responds in the stabilizing or dampening direction to a disturbance, the whole system is stabilized when that "negative feedback" response is coupled to the rotor. Contrary to the unstable airframe situation, it is highly desirable that the stable airframe motions be coupled into the rotor. This coupling can be simply that the cyclic stick is held "fixed" by the pilot or by control friction. The trim spring / offset gimble system also provides additional coupling of airframe motions into the cyclic control of the rotor. In other words, when the airframe motions of a stable airframe are coupled to the rotor, the whole gyroplane is self-stabilizing, without pilot action.

This stabilizing action is actually greatly increased if the pilot firmly holds the cyclic stick "fixed". This is likely what the less experienced pilot, in a tense situation, might be expected to do. However, good pilot technique, in any aircraft, is to loosely hold the stick without restricting it, while applying pressure to the stick for pilot "commanded" inputs. This is normally taught in order that the aircraft be allowed to stabilize itself with it's own inherent self-stabilizing actions. In a gyroplane with an unstable airframe, this is much more important so that the pilot doesn't force the destabilizing airframe motions into the rotor.

Traditional gyro thinking dictates that cyclic controls should be friction free. This thinking has evolved because that is important on the traditionally unstable gyro airframes to avoid coupling destabilizing airframe motions into the rotor. Alternatively, Magni has taken advantage of the highly stable Magni gyroplane airframe by the actual addition of some cyclic control friction to assure that the stabilizing reactions of the airframe ARE coupled to the rotor, even with pilot's loose hold on the stick. The amount of friction is enough to couple airframe motions into the rotor without pilot concern or input. The amount of friction is not so great so as to possibly cause pilot over-control. The result is that the Magni gyroplane is strongly self-stabilizing without pilot input, and pilot cyclic inputs are applied intuitively and linearly to control the "commanded" flight path maneuver only. The result is a comfortable balance or "harmony" of the pilot with the gyroplane that, even in rough air, feel much like a very nimble airplane in smooth air.

Pilot Induced Oscillations (PIO) and Power Push-Over (PPO):

The traditional safety issue with Bensen-derived gyros, throughout their history, has been the frequent fatal incidents of PIO and PPO. Pilot Induced Oscillations are simply when the pilot is unable to provide the proper and precise compensating "commanded" cyclic inputs for the reactions of an unstable airframe. The pilot's rotor control inputs are in the wrong direction and/or wrongly timed to "dampen" the natural oscillating tendencies of the unstable gyro. For such a gyro system, if the pilot's reactions are not precisely applied, the oscillations will continue or diverge to extreme amplitudes. And, to make it even more ominously difficult for the pilot of such an unstable gyro, the errant airframe motions are providing a feedback reference that is prompting these wrong pilot inputs. Typically, PIO oscillations are very quick and "diverge" to fatal extreme in just a few cycles. This is akin to aerodynamic "flutter" of an airplane's control surfaces. Some doubt that any pilot could even react properly once divergence initiates. It is this divergence that is actually initiated by the pilot's wrongly timed or applied inputs or reaction to a disturbance. The pilot's imprecise compensating reactions further cause a worse airframe reaction followed by a worse pilot reaction - thus Pilot Induced Oscillations. The pilot's initiating control actions are often in reaction to a wind gust disturbance, but can be initiated from over aggressive flight maneuvering beyond that pilot's skill in that unstable gyro.

Pilot over-reaction or over-control is one significant root of PIO. A truly stable gyroplane will "dampen" or diminish the effects of pilot over-control, and a truly stable airframe will minimize the over-reaction or ill-timed tendencies of even less proficient pilots by the comforting solid feel of the aircraft reactions. The Magni design applies all appropriate aerodynamic means to self-stabilize the airframe and aircraft, and provide proportionate and appropriate airframe attitude cues to the pilot. The attitude and g-load cues to the pilot preclude pilot over-reaction and wrong reaction on the controls. Magni also employs another pilot feedback mechanism that is rarely provided on other designs - cyclic stick feedback forces. In most other aircraft types, some degree of control force feedback is employed naturally - the force resistance of an aileron or elevator, for instance. Traditionally, gyroplanes rotors have been designed to the contrary, to offer very light or even force-free cyclic stick resistance forces. The lack of cyclic stick force feedback to the pilot however, is one element in possible pilot over-control. With no rotor/cyclic force feedback, the pilot cannot readily perceive the neutral positioning of the cyclic or how much actual cyclic control is applied. Neutral or constant cyclic control inputs cannot be immediately, if subconsciously, perceived through stick forces. Without this additional feedback mechanism (loop), the pilot must rely on the resultant action of his/her cyclic input - attitude or g load change - to reference the effect of that cyclic input. This means some inertial delay in the feedback (loop) which can lead to over or ill-timed control inputs. Indeed, with little or no cyclic force feedback, un-intentional or over-aggressive pilot reaction is not perceived by the pilot until airframe over-reaction might occur.

Magni gyroplanes employ significant cyclic force feedback. This is accomplished through a combination of the inertia of the rotor and the rotor airfoil and feathering axis arrangement. The result is that cyclic feedback forces constantly and immediately provide pilot cues of the aggressiveness or amplitude of his/her cyclic input. With such a system, un-intentional reactive cyclic inputs are tempered or prevented. The pilot is well aware of his/her cyclic input, must intend to be making that particular cyclic input, and is less likely to make inadvertent or over-reactive cyclic control inputs. This may be the very first Magni characteristic that unfamiliar gyro pilots recognize when first flying the Magni. Some may suggest that this significant force feedback limits the "nimbleness" of the Magni gyroplane. In actuality, the gyroplane is just as "nimble", the rotor can be maneuvered just as quickly and aggressively, but the pilot must certainly apply intentional cyclic stick forces to do so. This means that the pilot is less likely to apply aggressive cyclic control inputs inadvertently. The cyclic force feedback is immediate, with no delay in perception of the actual cyclic input. This additional and immediate feedback "loop" allows the pilot to "fine tune" his/her control inputs, before the other feedback cues arrive. The result is that the pilot is now acting in harmony with the other harmonious reactions of the stable gyroplane. This harmony provides the exceptional comfort and reassuring feel of the Magni, even in very turbulent air. You feel truly "in harmony" with the air and the aircraft. The result, in the already truly stable and PIO resistant gyroplane, is additional PIO resistance for even the most novice of gyroplane pilots. It has been demonstrated that flight control of the Magni, even in turbulent air, can be mastered by complete novices in just a few minutes of instructive demonstration.

PIO is not itself the real "killer". However, PIO can quickly progress to such pitch attitude oscillating extremes that reduced g loads or even negative g loads (airflow on top of the rotor) can cause the rotor to slow below it's ability to autorotate upon the next high g cycle. This is typically considered to result in Power Push-Over when the gyro either tumbles forward from loss of rotor thrust or the rotor slows dramatically and folds when centrifugal forces cannot support the gyro load.

Power Push-Over is just one form of what is also called a "bunt-over". These typically refer to the gyro pitching rapidly forward to inverted. This typically results from an unbalanced propeller thrustline that tends to rapidly rotate the gyro forward once the rotor looses significant lift and drag (thrust).

PPO is typically considered to occur from any or all of several factors:

- Pilot rapid forward cyclic stick motion causes reduced rotor lift and drag, allowing the rotor to slow, perhaps too much!
- A strong wind down-gust disturbance which also "unloads" the rotor - reduces rotor lift and drag.
- Upon severe and/or extended loss of lift, the rotor slows below its ability to autorotate and support the gyro's weight.
- An unbalanced propeller thrustline offset pitches the airframe rapidly nose-down upon loss of rotor lift and drag.
- The unstable airframe, pitching rapidly nose-down results in moving the rotor thrustline forward, relative to the CG, causing further nose-down pitching in reaction to reducing or negative rotor thrust.

For a properly aerodynamically balanced and damped airframe, with complimenting rotor and airframe inertial responses, the above factors can be avoided. If the propeller thrustline is properly balanced (by the Horizontal Stabilizer and other airframe surfaces), the CG / rotor lift vector stable relationship will be maintained and disturbances will be reduced rather than amplified. The inertial reactions of both the airframe and rotor can be "harmonized" so as to prevent disastrous slowing of the rotor for both natural and pilot disturbances.

There are other "pitch related" incidents that, while they cannot be accurately described as PPO, or even a "bunt-over", still result in the same thing. These may be incidents where the airframe reactions allowed the "rotor to be pulled back into the tail" or propeller by an over-reacting pilot, or the rotor incurs a "precession stall" from improperly balanced loading and inertia reactions. In the end, all of these fatal incidents are the result of some aerodynamic pitch stability flaws in a design, which allow certain extreme conditions to progress into these critical issues.

The Magni gyroplane, while it is not claimed to be totally impervious to extreme pilot abuse of the flight parameters, is designed with all these factors addressed and compensated. Some of the issues are avoided by good aerodynamic airframe reactions. Some issues are addressed by the balance of the moments acting on the airframe to properly align the CG and rotor lift vector. Some issues are addressed through "harmony" of the various inertias. Some issues are addressed by harmonizing the gyroplane and controls reactions to the human capabilities of the pilot - including the accurate pilot reference of a stable airframe. And, last but not least, all of these issues are addressed through good pilot flight and knowledge training. For any gyroplane, whether as stable as a Magni or not, the best avoidance of PIO or PPO or any other related situations, is the full understanding and appreciation and avoidance of the factors involved.

Summary:

Personal preferences and perceptions on gyroplane stability will continue. The challenge and satisfaction of mastering control of a wild beast has attraction and lure for some. However, to many, the difficulties with mastering sometimes-dangerous quirks can make the risks not worth the allure. Even the pilot, who has attained a safe proficiency in less stable gyros, in windy conditions will likely tire from pilot workload - however automatic and unconscious that effort may be.

In my personal opinion, having flown many breeds of this beast, I find it more comforting, enjoyable and reassuring, knowing that my "beast" is tamed - knowing that an unexpected villain won't suddenly appear. The precision and solidity of flying a truly stable aircraft, to me, far outweigh the thrill of unnecessary risk. The Magni gyroplane abundantly provides the many extremely enjoyable unique thrills of gyroplane flight without the worry and concerns that something as insidious as PIO or PPO might bite. And, the pure solid feel of the superbly stable Magni gyroplane, in even the gustiest of turbulent days, makes that enjoyment no longer restricted by concerns with the wind.

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