“Why are the Magni Gyros so stable?”

(They appear to have a high propeller thrustline!)

- Greg Gremminger   (Revised, January, 2010)

Greg Gremminger is the Magni Gyro distributor in the U.S. The Magni gyroplane is built in Italy and is popular in many countries around the world. Greg is a frequent technical contributor to Rotorcraft magazine. Greg is also serving the gyro community as the chairman of the ASTM Light Sport Aircraft Gyroplane subcommittee, developing the standards for gyroplanes under the proposed new FAA Sport Pilot rules.

I am the Magni Distributor in the U.S. I often hear comments about the perceived high propeller thrustline of the Magni gyro as relates to its flight stability and handling. I love to answer this question about the Magni “prop thrustline” because it leads to a (hopefully) instructive discussion on gyroplane stability and safety in general. My views offered here are my personal perspectives and determinations as the result of passionate years of trying to help people understand how to fly safer gyros more safely. The details presented below are not necessarily the views of the Magni designers and factory in Italy. My purpose in flying and providing Magni gyros in the U.S. has been to demonstrate the true safety potential of gyroplanes to the American aviation community. I too had originally asked the same questions that are the subject of this article. My experience with the Magni gyro has developed some of the insights I am expressing below.

An understanding of some basic principles of gyroplane stability is necessary. The essential stability and control harmony characteristics of any aircraft, but especially for gyroplanes, include several basic static and dynamic concepts:

- **Pitch AOA STATIC stability** is the ability of the gyroplane to inherently maintain the trimmed steady state AOA relative to the relative wind and to tend to return to that steady state AOA after a disturbance or deviation from that trimmed condition.

    - **Pitch AOA STATIC INstability** is the root cause of a buntover [including Power Pushover (“PPO”)]. AOA STATIC INstability causes a deviation from the trimmed AOA to inherently tend to further deviate from that trimmed condition in an increasingly divergent manner. In the nose-down direction, this rapid divergence is a buntover.

    - **Pitch AOA STATIC stability** is a function of both the relative positions of the Rotor Thrust Vector (RTV) to the Center of gravity (CG) of the whole aircraft in flight; and it is a function of the combined DYNAMIC damping afforded by the airframe horizontal stabilizer (HS) and the rotor. The dynamic reactions of the airframe and of the rotor can interact to impact DYNAMIC and STATIC stability positively or negatively.

    - The **STATIC relative position of the RTV to the CG** is a function of the sum or **ALL STATIC** moments on the airframe relative to the CG – including the **propeller thrustline**, the **RTV**, the nose-up or nose-down **aerodynamic forces on the airframe** (enclosure, windscreen, etc.), and the nose-up or nose-down forces on the **HS**. Therefore the propeller thrustline is only one part of the equation and not the total determinate of flight stability – whether it is high or it is low!.

- **Airspeed STATIC stability** is the ability of the gyroplane to maintain and tend to return to a steady state AIRSPEED. Airspeed STATIC stability is a function of the ability of the nose-up forces on the HS (HS download) to statically compensate the other cumulative aerodynamic nose-down forces. Since the aerodynamic forces on most gyroplanes will be in the nose-down direction due to sloping windscreens, draggy landing gear below the CG, and profile dragline below the CG, the HS must provide a download on the tail to balance or compensate these other aerodynamic forces on the airframe. Since these aerodynamic forces on all airframe components are a function of the square of the airspeed, if the nose-down forces are greater than the ability of the HS to hold the nose-up, the aircraft will rapidly increase airspeed in an increasingly steep dive - if not immediately corrected by the pilot before the dive becomes significant. This requires constant pilot attention to "balance" the gyro at its trimmed airspeed and AOA.

- **DYNAMIC damping** afforded by the combination and interaction of the rotor and airframe can expand or enhance STATIC AOA stability while preventing inherent quick natural pitch oscillations that can influence pilot over-reaction or Pilot Induced Oscillations (PIO). The dynamic reactions of the airframe and of the rotor can interact or interfere with each other to positively or negatively impact both DYNAMIC and STATIC stability.

Let's examine the STATIC in-flight relative positioning of the RTV and CG: The propeller thrustline is only ONE part of the total equation for this positioning – prop thrust moment (a variable function of engine power applied) is just one STATIC pitching moment on the airframe of a gyro that must be considered with all the other STATIC pitching moments on the airframe. These other STATIC pitching moments include the drag line (and moment arm offset from the CG), the lift or down-lift (moment) of the horizontal stabilizer (HS), and any other lift or down-lift forces (windscreens, enclosure profiles, landing gear, etc.) acting to pitch the airframe nose up or down. (These other STATIC aerodynamic moments acting on the airframe are a variable function of mostly airspeed). Boiled down, the relative positioning of the RTV to the CG is a function of power applied through any offset prop thrustline, AND a function of the airspeed presenting various aerodynamic nose-up/down forces on the airframe, windscreen, enclosure, landing gear, HS, etc. Static destabilizing nose-down forces become substantial and possibly over-powering at higher airspeeds because those forces increase with the square of airspeed.

The Magni gyro prop thrustline IS slightly high – for a very good reason – to assure a STATICALLY downloaded HS with a level AOA under all power and airspeed combination conditions! But, the Magni prop thrustline is not as high as it might appear to the casual observer – all things need to be measured, subjective eyeball judgments are deceptive. The Magni prop thrustline, depending on loading, may be as little as 0.75" high, and perhaps as much as 4" high. The Magni prop thrustline is purposefully slightly high so that the HS lift required to balance this HTL nose-down static moment is a DOWN-LIFT of the HS. With the other cumulative aerodynamic forces on the airframe being in the nose-down direction, airspeed static stability can only be (inherently and passively) accomplished by a down-lifting HS! A truly centerline thrust (CLT) does not require any lift of the HS to balance the prop thrustline. A low prop thrustline with power applied requires the HS to provide an UP-LIFT – a negative airspeed static stability condition! Any prop thrustline is CLT when it is not producing thrust; but nose-down airframe aerodynamic moments will be destabilizing for any prop thrustline if not properly balanced by a DOWN-lifting HS balancing against these other aerodynamic moments. The Magni high propeller thrustline, requiring a DOWN-lifting HS to be consistent with the airspeed stability requirement, is easily "balanced" by the very effective down-loaded horizontal stabilizer. It is true in general, that the higher the propeller thrustline, the more work (and perhaps drag) the HS (and rotor) is required to do to statically balance that high thrustline moment – the Magni prop thrustline and very efficient HS on a long moment arm has minimal effect on the performance of the Magni gyro as evidenced by its superb performance on just 100 HP.

Now, let's examine DYNAMIC factors: The DYNAMIC characteristics of the gyroplane are also indispensible contributors to the overall control and flight stability harmony of the aircraft.

DYNAMIC stability means that the aircraft will not inherently oscillate quickly or continuously in pitch (AOA) or airspeed. DYNAMIC stability is provided by the DYNAMIC damping systems of the aircraft. For gyros, DYNAMIC damping is provided by the rotor and by the airframe HS - and by the constructive or destructive interactions between these two. Unlike a fixed wing on an airplane, the rotor and the airframe of a gyro can individually react to air, G-Load and pilot control input disturbances according to their individual inertia and damping characteristics. The rotor has natural DYNAMIC reactions due to its inertia and blade damping. Airframe pitch damping can only be provided by a HS – without a HS, the airframe has no pitch damping! But, the rotor and airframe pitch reactions interact with each other in several ways. These interactions include airframe reaction to changing and moving RTV relative to the CG, and rotor response to changing spindle angles when the airframe pitches or rolls. So, the combined DYNAMIC reactions of both the rotor and the airframe can interact with each other to dampen **OR** worsen inherent total aircraft reactions to disturbances or pilot control inputs. Only flight testing can determine if the harmony or disharmony of rotor and airframe DYNAMIC characteristics serve to improve stability and damping adequately – or not.

Additionally, the pitch reactions of the airframe are critical because airframe attitude provides visual flight path feedback to the pilot – preferably to indicate what the whole aircraft is doing. The rotor is always DYNAMICALLY affecting airframe pitch through the RTV/CG moment transients from turbulence or control cyclic inputs. These rotor effects on the airframe pitch attitude do not necessarily impart airframe reactions that accurately reflect the changing flight path. The airframe must track true to the actual flight path if the pilot is going to use the pitch horizon reference to judge control inputs and flight path precision. The only way this can be done is with an effective HS that forces the airframe to track the true flight direction. The DYNAMIC response of the airframe should be quick and accurate, provided by strong DYNAMIC damping from the HS. With the accurate flight path indication of the airframe / horizon sight picture, the pilot can react accurately to disturbances or his/her cyclic control inputs. Without a HS, there is no airframe DYNAMIC damping and the airframe most likely will not accurately track flight path in a timely manner. This could easily lead to over control and PIO.

The common primary DYNAMIC concern for a gyro is it's susceptibility to PIO. PIO is when the pitch reactions or oscillations of the airframe are so quick that the pilot reactively trying to correct the airframe pitch or oscillating reactions will unintentionally make them worse and divergent. For this reason, the gyroplane should inherently, without pilot intervention, have its faster pitch oscillatory tendencies and pitching rates (that would require or excite pilot intervention) severely damped so as to be non-detectable by the pilot.

PIO can be excited by the very rapid airframe pitch AOA oscillations faster than a 5 second period (complete cycle of on oscillation). This means that all pitch oscillations faster than a 5 second period, or the equivalent pitching rates, should be inherently severely damped so they are not perceived or sensed by the pilot at all. Such pitch damping will prevent both pilot tendencies to PIO, AND prevent pilot over-reaction that could result in a buntover (very quick divergent nose-down pitch.)

Depending on experience and proficiency, the pilot can generally “damp” oscillation rates slower than 5 second period. The ASTM standards for DYNAMIC stability require that oscillations with periods shorter than 5 seconds should be damped to at least ½ amplitude within one cycle. Oscillation periods between 5 and 10 seconds should be damped within 2 cycles. Oscillation rates with periods between 10 and 20 seconds should be at least damped (not continuing or expanding). These criteria minimize or eliminate PIO susceptibility and reduce pilot workload and reactions for steady flight and turbulence correction. As a benchmark, the Magni M16 has a natural oscillation rate with a period of about 13 seconds, and a damping rate of less than 1-1/2 cycles. The M16 has no detectable oscillations faster than this (which helps explain why no reported incidents of PIO or buntover).

But, possibly more important to gyroplane stability than PIO susceptibility, strong DYNAMIC airframe damping actually improves or enhances or expands the STATIC AOA stability margins. Even for gyros that might otherwise be AOA statically unstable due to the in-flight physical location of the RTV forward of the CG, DYNAMIC damping can provide or improve STATIC AOA stability. The divergent DYNAMIC pitch reaction in a buntover (or PPO) is a function of BOTH the RTV/CG statically destabilizing moment, but also of the pitching rate ability of the airframe to sustain that nose-down pitch divergence. Strong Dynamic damping provided by the airframe HS provides essentially provides an additional stabilizing moment to offset the RTV/CG moment in the more stable direction. A "tailless" moderately HTL gyro that otherwise flight tests to be STATICALLY AOA unstable (and susceptible to PPO) can flight test to be STATICALLY AOA stable with a strong DYNAMICALLY damping HS.

For DYNAMIC damping, the longer tail the MUCH better! For STATIC pitch balance, the STATIC HS stabilizing moment is a product of the a **<u>single multiple</u>** <u>of the HS moment arm</u>. The DYNAMIC moment from a vertically moving (airframe pitching) HS is the product of the <u>HS moment arm</u> **<u>SQUARED.</u>** DYNAMICALLY, as a function of the rate of airframe pitching motion (DYNAMIC), the vertical movement of the HS changes its AOA during this movement or airframe pitching motion. Since the vertical velocity of the HS, and its resulting AOA, is also a function of the length of the tail, DYNAMICALY, the damping provided by the HS is a function of the HS moment arm SQUARED. The tail length has much more effect on DYNAMIC stability and damping than it has on STATIC stability. But, the longer tail helps BOTH. On the Magni, the large and aerodynamically efficient HS located on the very long tail provides very high DYNAMIC damping – which is the major factor for its DYNAMIC stability and PIO resistance, but may also be the major factor in the enhanced AOA stability and buntover resistance.

All these STATIC and DYNAMIC issues (and others) are addressed in the Magni design. This is a major reason the Magni has had no pitch related accidents and has a very good safety record in general. This is also not addressing the other quality characteristics of the Magni such as smooth rotor technology, robust steel welded airframes, all steel and quality bearing control components, reliable engine, superb performance, and attractive Italian (and aerodynamic) styling.

One final word about gyroplane stability - as it relates to gyroplane maneuverability and controllability: Gyroplanes are the one aircraft type that CAN be both highly maneuverable and precisely controllable while also being superbly stable and insensitive to outside "un-commanded" disturbances such as wind turbulence. This seems contrary to the historically presumed axiom that higher stability means less maneuverability (and less "fun"!) This is not necessarily so, simply because gyroplanes are not the "fixed-wing" aircraft, to which that axiom does truly apply – this stability vs. agility airplane analogy does not work for gyroplanes! The gyroplane CAN be unique to all other aircraft types in this regard - that's why many of us are so excited about gyroplanes! The gyroplane rotor, coupled with a truly stable airframe, CAN almost completely handle wind turbulence automatically without pilot input. But, the pilot has additionally much more powerful cyclic control of the rotor which commands the real intentional maneuvers of the gyroplane. That pilot "commanded" control is 4 - 5 times more powerful and effective than any disturbance the wind can throw at that machine! And, with a truly stable airframe, one that pitches in the proper direction in response to a disturbance, and one that truly does track the relative wind, those pitch cues to the pilot allow much more precise and safe "commanded" control of those agile maneuvers.

A truly stable gyroplane will "resist" overly aggressive pilot control inputs and prevent and/or compensate for reactive over-control inputs (somewhat in the form of stick resistance pressures). But the pilot can intentionally muscle the cyclic stick inputs that will result in very rapid gyro maneuvers if desired. In fact, higher stick "feedback" forces are not only the result of a truly stable aircraft, they intentionally serve to prevent inadvertent over-reactive and/or imprecise pilot inputs that are more likely when the stick has very little "feel". The stability of the gyro does nothing to affect the unique flight capabilities of the gyro – such as low speed or zero speed flight, high G tight turns, and slow and short landings. (If anyone doubts this assertion that you can have true safe stability and passive automatic insensitivity to disturbances in an aircraft that is, at the same time, very highly maneuverable, I would invite you to visit me at our Missouri base for a demonstration).

It is interesting to note that the Magni aerodynamic and stability configuration concepts that have been around since Jukka Tervamaki designed the JT-5 in the early ‘70s. These concepts have been refined and employed by Vittorio Magni and his family throughout the ‘80s, and are now being emulated by several other manufacturers around the world. I consider this a testimony and reinforcement to the desirable results of attention to these basic stability issues. This is not to say that other combinations of configurations cannot achieve similar results. But we truly hope that such examples of safe and stable gyroplane characteristics, will sooner than later, allow the gyroplane to achieve its full potential and a reputation as the safest of all aircraft types.

We wish you all safe flying - Greg