

# The immersion of horizontal stabilizers within the prop wash of pusher gyros

The hypothesis of Don Shoebridge

## *Introduction*

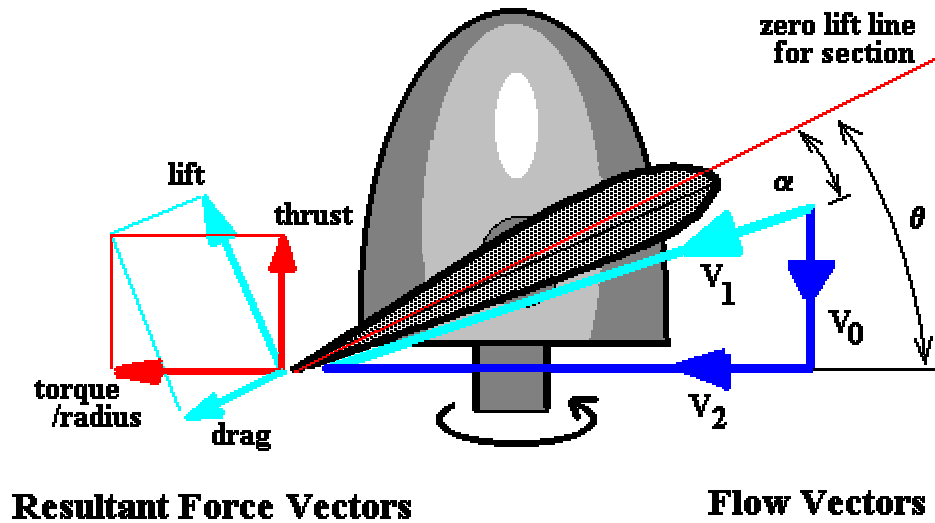
Lets get the obvious stuff out of the way first. I'm sure everyone will agree that clean airflow is the best airflow, and in the case of H-Stabs and gyros, more is better. To a lesser extent, but still clearly a majority, some people will agree that H-Stabs are a necessary part of safe, controlled flight. Let me be quite clear, I totally agree that an effective H-Stab is a necessary component of safe and controlled flight.

Calculating the effectiveness of a H-Stab in clean airflow is always going to be easier and much more accurate than trying to calculate, guess or judge by feel the same H-Stab in the middle of the propeller spinner. There are way too many variables when talking about an immersed H-Stab, and therefore, there is no way to mathematically predict how well a H-Stab will function in this situation. Trying to predict the performance and operating characteristics of an immersed H-Stab is not just a matter of applying a rule-of-thumb or simple formula. There have been several in-depth discussions on this topic throughout various internet sources. I've asked so called "experts" some simple questions like, "where is all of the math and engineering effort that supports the immersed H-Stab argument?" Typically, it's the same old answer - "...you should do a better search...", "...this has already been covered...", etc. I don't like the idea of faith based engineering, i.e., relying solely on people's opinions and out-of-the-blue ideas that cannot be mathematically proven, or at least predicted with a degree of certainty. If the so-called "experts" cannot provide references to research performed by NASA, NACA, or the like, or can't quote scripture-and-verse out of an aerodynamics book, or at least provide a book title and page number(s), or provide an internet site with any relevant information, then stay away from those people, and don't take anything they say as gospel. In fact, don't take anything I say as gospel either. Research it and confirm it yourself. Because if you are serious about building and flying a gyro, it isn't a very good thing to find out that someone gave you bad advice after you get off the ground.

There are many factors that act upon the H-Stab. The obvious variables are; engine RPM, propeller diameter, propeller pitch, aircraft forward airspeed, inflow angle, up-stream objects (pilot, engine, etc.), propeller efficiency (drag), air density (altitude) and air temp. The last two I'm going to ignore because they play such a small part when considering the typical operating environment of a gyro.

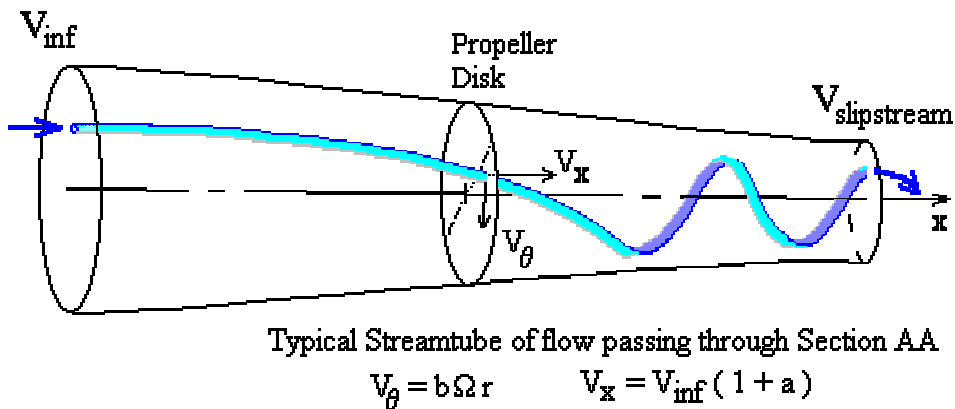
## *The Propeller*

The job of the propeller is **NOT** to provide airflow like a box fan that you might use in the summer. The job of the propeller is to move an aircraft, or gyro in this case, forward at a speed sufficient to get the aircraft in question flying. That is why a propeller is shaped like a wing, and not like an automotive radiator fan. A propeller is meant to fly just like a wing does. Prop wash is merely a by-product of the propeller's flight. And just like an airplane's wing, there is drag. This drag is what causes the prop wash to be in the shape of a corkscrew or helix.



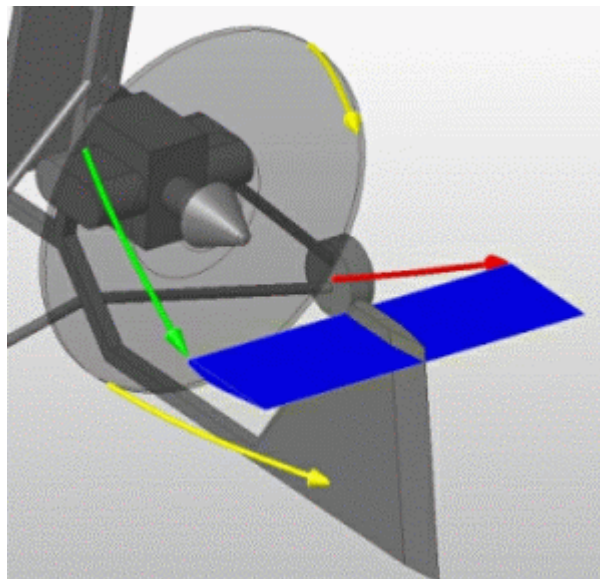
### Helical Flow

The first thing everyone needs to get a grasp on is the fact that prop wash isn't just a simple straight flowing tube. It's a tapered helical flow (<http://www.ae.su.oz.au/aero/propeller/prop1.html>). This is the cause of the first problem we have with an immersed H-Stab – Dissymmetry of Lift! If the H-Stab in question is mounted directly on the spinner centerline, then the H-Stab is going to see different angles of attack between the left half and the right half. In fact, the AOA is going to be different across the entire H-Stab. Concrete evidence of this can be found by simply feeling the effect the prop wash has on the vertical stabilizer during take off, when the throttle is wide open and forward airspeed is low - the tail of the gyro will be pushed in the direction of the prop wash, requiring the pilot to counter the yaw with rudder pedal input. So how much twist is there in the prop wash? Or more importantly, at what AOA does the prop wash strike the H-Stab?



Most everyone has heard the pro-H-Stab-prop-wash argument – "...a H-Stab mounted in a 100 MPH prop wash is going to produce 4 times greater down force than if it were mounted in a 50 mph free stream airflow". The argument continues with "...if a gyro in flight pitches nose down by 10 degrees, factoring in this AOA difference, a H-Stab mounted in the prop wash will see an AOA increase of about half of the incoming airflow, about 5 degrees, resulting in an additional down force of 200% when compared to a free stream mounted H-Stab seeing an AOA of 10 degrees." Or does it? It is

thought by some people that a center-of-the-propeller mounted H-stab performs better as a prop wash straightener than it does a pitch-stabilizing device.



In the image above, you can see how the prop wash would contact the H-Stab. Using some simple math, it's possible to get a rough number as to the AOA that the H-Stab sees from the prop wash. It is quite possible that the H-Stab would see an AOA of 30 degrees or more. I'm betting that it's much greater than that. Just look at the old WWII films of the F6F's launching off the decks of aircraft carriers, and the water vapor condensing in the prop wash. The helical flow is almost perpendicular to the wing! Granted, the propeller pitch is different and the aircraft forward airspeed is different, but it clearly illustrates that the AOA at the H-Stab can be so high that the H-Stab is stalled, regardless of the aircraft forward airspeed. I'm sure some people will argue with this; to that I say, prove me wrong. What is the flow angle that is striking the H-Stab? Even if the H-Stab is not stalled, a H-Stab mounted on the centerline of the propeller is going to have a twisting moment on the tail, again dissymmetry of lift. One half of the H-Stab is doing practically nothing to help pitch stabilize the gyro, and the other might be helping. If the down force being gained comes from only one-half of the H-Stab because of the helical flow and the resulting dissymmetry of lift of the H-Stab, the 200% advantage of having your H-Stab in the centerline of the prop wash has been negated! But this all depends on what the AOA is on the H-Stab.

Ok, so at what AOA does this H-Stab stall? Again, there are a lot of factors, but for sake of argument, and not wanting to break trends by under simplifying things, let's say 15 degrees. Let's focus on the flow angle that hits the top side of the H-Stab. Again, for argument sake, if this helical shaped prop wash is striking the top surface of the H-Stab at an angle of 15 degrees, instead of the previously mentioned 30 degrees, based on a simple trig vector formula, then a 10 degree nose down aircraft flight attitude would ultimately apply about a 20 degree AOA to one-half of your H-Stab, causing it to stall! The good thing now is that the other half of your stab is only seeing 10 degrees AOA in the wrong direction, instead of 15 degrees. If you have a few degrees of negative incidence cranked into your H-Stab, now the AOA problem is even worse for one side and it may even be stalled in level flight. In which case, the un-stalled half of the H-Stab is now working opposite of your design intentions, and is pushing the nose down!

As the forward airspeed of the gyro increases, the helical flow of the prop wash straightens, causing the H-Stab AOA to be smaller, which contributes to a H-Stab that is actually “flying”, and not stalled. But at what forward airspeed does this occur? Isn’t pushing the airspeed envelope of a gyro inviting more danger through pitch instability, eh Hot Dog? At what point does this H-Stab actually begin to “fly” and provide some real down force on the tail? With the propeller spinner being aligned and within close proximity of the H-Stab, I don’t think you can get away from a constantly stalled H-Stab, because the more throttle you apply, the more engine RPM you generate, and therefore, the more twist you get in the prop wash. And while you’re waiting for your forward airspeed to increase so that the H-Stab starts to fly again, any CG-thrustline offset you might have is trying to drive you into the dirt!

But everything above is based on the assumption that this tapered helical prop wash is always going to flow in a nice straight line at some angle to the propeller axis-of-rotation when an aircraft AOA is applied. On the contrary! With that same 10 degree inflow angle applied to the prop, the prop wash is NOT going to be a nice straight tube, like most people have envisioned. It’s going to be a curved-tapered helix, curving in the same direction that the relative airflow is moving. I will however concede to the fact that the prop wash will turn in a direction that is beneficial and will help to provide down force to the H-Stab. But it’s still going to depend on how clean the airflow is, and what AOA each side of the H-Stab is seeing from the prop wash because of the helical flow. If one half of the H-Stab is stalled, and the other half is receiving prop wash flow from the under side, then this spinner aligned H-Stab isn’t going to do you much good.

So what about the dissymmetry of lift on the propeller itself? It’s obviously there. One visit to P-Factor should be proof enough of that. Well then if there is dissymmetry of lift at the propeller, then there must be dissymmetry of flow in the prop wash. And this is going to aggravate the H-Stab dissymmetry of lift even that much more.

### ***Airflow Pulsation***

Some years ago, I found some very interesting information that focused on the radiator location and cooling of liquid cooled aircraft engines (<http://www.bewersdorff.com/wankel/radiator/CoolingSystems1.html> and <http://www.bewersdorff.com/wankel/radiator/CoolingSystems2.html>). I got the impression that a lot of time was spent on the Ju-87 because the German military was having all kinds of problems keeping the engine cool. The Germans thought that if the radiator was moved to a point right up behind the propeller, that the cooling capacity of the radiator would increase and they could keep the engine cool. What they found is totally opposite. The radiator had to be moved farther away from the propeller, not closer. The reason this problem occurred in the first place is because each time that a propeller blade passed by the radiator, the radiator would see a pulse of high velocity air, but the dwell time between blades, where there was very little flow, negated the high velocity air flow. With limited success, the Germans even tried longer chord length propellers in an attempt to force more air through the radiator. The resultant sum of the prop wash was less than anticipated. Which goes back to what I said earlier – clean flow is better than turbulent flow.

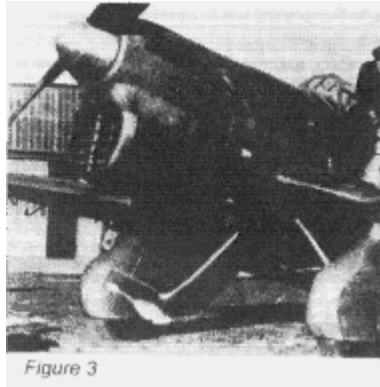


Figure 3

There is no difference between the Ju-87 radiator situation and the H-Stab location on a typical pusher gyro. The tail feathers are seeing these same pulses from the prop. Tractor gyros do not suffer as much from this because these pulses have time to dissipate because of the distance between the propeller and the H-Stab. Another benefit of this is that the helical flow of the prop wash is not as prominent, the flow is now straighter and flowing more inline with the propeller axis of rotation (<http://www.ae.su.oz.au/aero/propeller/prop1.html>).

The more stuff that is placed into the prop wash, the more vibration is going to be transmitted to the aircraft. What kind of long term effect will there be on the airframe or tail feathers? I once read a conference post about this, and the gist of the post was that there was a great deal of vibration with the H-Stab being mounted on the centerline of the propeller. Therefore, the H-Stab was relocated to a point below the centerline (somewhere), possibly the keel, and the vibration was gone.

### ***Turbulent and Non-Turbulent Flows***

Turbulent flow is defined as "...a flow characterized by turbulence, that is, a flow in which the velocity varies erratically in both magnitude and direction with time." (source: Basic Science For Aerospace Vehicles - Northrop Institute Of Technology, pg. 35-36, c1963) Turbulence is caused by an "...abrupt change in direction of the airflow..", which is commonly known as "separation of flow", or "flow separation". Keep in mind however, that a helical prop wash isn't necessarily classified as a "turbulent" flow. But, if the incoming airflow is turbulent, the prop wash will be as well.

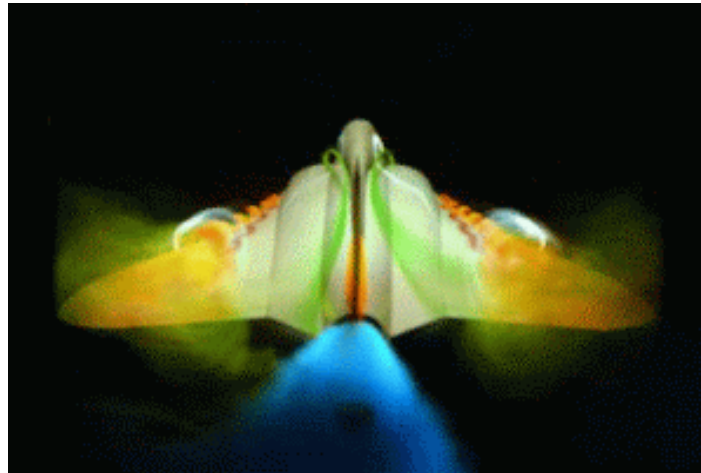


The most obvious non-turbulent helical flow that may come to mind is that caused by a vortex generator. So what is a vortex generator? Where are they used? What do they do? Vortex generators produce a small helical flow similar to that of prop wash. Most often, the entire vortex is on one surface, not split in half like the prop wash with a fully immersed H-Stab is. Vortex generators are specifically located in an area forward of where flow separation is occurring. (<http://www.microaero.com/>, <http://home1.gte.net/pjbemail/VortexGen.html>, <http://thirdshift.com/jack/firefly/firefly18.html>) Vortex generators add energy to the

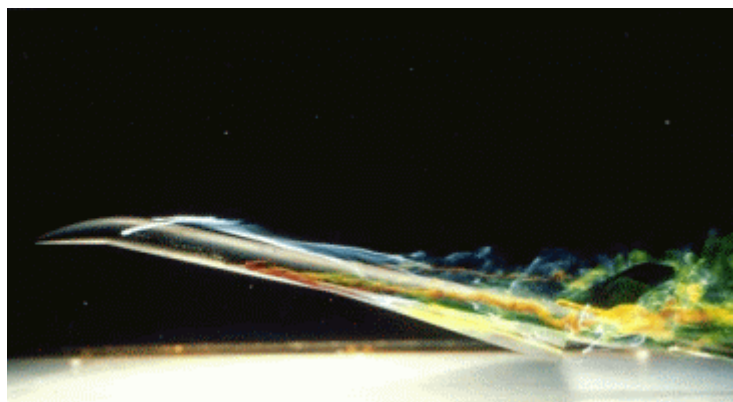
boundary layer (dead air close to the surface) of aerodynamic surfaces like a wing or fuselage. This added energy delays the flow separation and helps to keep the airflow hugging the surface, even around some relatively sharp turns.

In the case of the Cessna 337 SkyMaster, there are vortex generators mounted near the aft end of the fuselage, near where the fuselage tapers down to meet the aft engine nacelle and propeller. This was done to present a cleaner airflow to the propeller. Without the vortex generators, the resulting turbulent airflow caused by the fuselage would make the rear propeller almost useless.

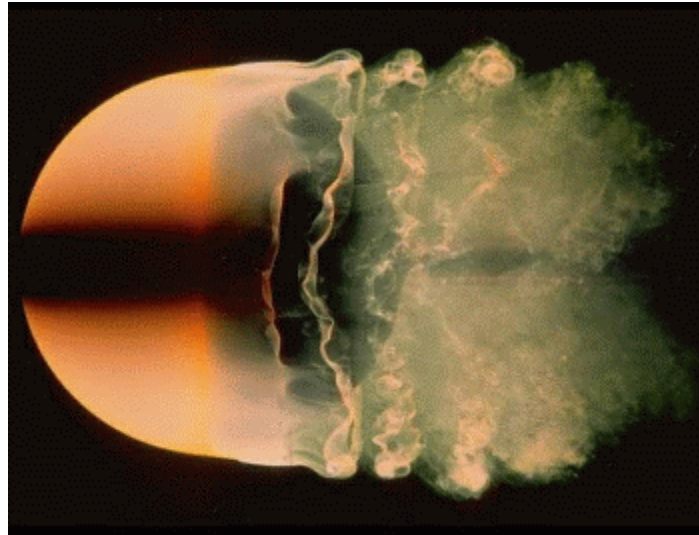
Vortex generators are not the only means of adding energy to the boundary layer. Military and some civilian aircraft use low aspect ratio wings and leading edge extensions (more commonly known as strakes) to create vortices that trail over the tops of wings, adding energy to the boundary layer and allowing the aircraft to fly at much higher angles of attack. This is a necessary part of military aircraft because of the need to turn as tight and as fast as possible.



Tight and fast turns are not necessarily needed with civilian aircraft such as the Concorde. The delta wing configuration of the Concorde, though efficient at higher speeds, doesn't work all that well low and slow. The leading edge shape of the Concorde's delta wing promotes the generation of vortices at high angles of attack during landing and takeoff, reducing the low end airspeed of the aircraft. Because the Concorde lacks any secondary lifting or pitch control devices, specifically a canard or horizontal tail feathers, these vortices have a great deal more importance.



Airflow separation causes a great deal of turbulence and drag. Turbulence, and the resulting drag, is unwanted and is detrimental to aircraft and many other items that pass through air such as; cars, trucks, golf balls, and bullets, just to name a few. Though it is possible to predict with a certain degree of accuracy when and where flow separation and the resulting turbulence will occur, calculating the effects that turbulence will have on an object is, for the most part, impossible (<http://hathor.onera.fr/photos-en/hydrodynamic-tunnel.html>).

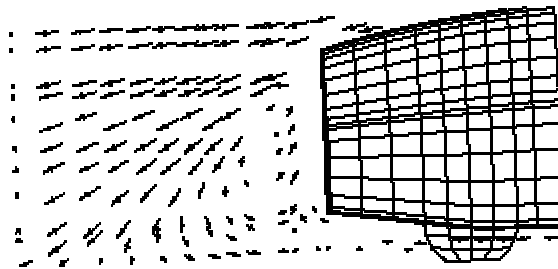


I mentioned a "golf ball" for a specific reason. Golf balls are dimpled for aerodynamic reasons. It was found early in the life of golf that the balls seemed to fly farther if the balls were beat up, nicked, sliced, or roughed up. Why is this? It doesn't seem right to add roughness to a surface that should otherwise be smooth because of aerodynamic reasons. Well, one factor that most people tend to overlook is that golf balls spin as a result of being hit with a club. The spin is usually in the direction of top-toward/bottom-away from the golfer, more commonly known as "back-spin". The dimples do impart a degree of drag on the ball, but because of the back-spin, flow separation over the top of the golf ball is delayed, causing a reshaping of the airflow around the ball. The new airflow shape looks and acts very much like an airfoil, causing the golf ball to "fly" (<http://www.titleist.com/htm/tech/aero3.asp>, [http://www.leaderboard.com/GLOSSARY\\_DIMPLE](http://www.leaderboard.com/GLOSSARY_DIMPLE), <http://www.adsources.com/golf/golfinfo/golfpa3.htm>). The turbulence behind the ball is still there, though it is reduced a small amount. Unfortunately, golf ball aerodynamics do not play a part in immersed H-Stab's.

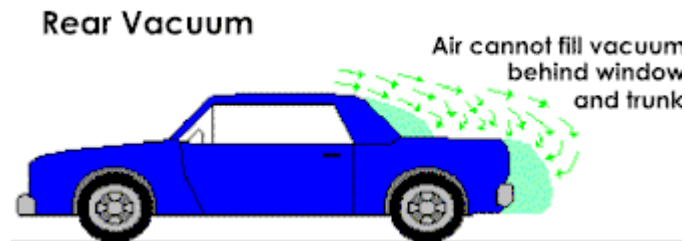
The aerodynamic effects on a spinning golf ball can also be seen in the area of long-range precision rifle shooting. From the front, bullets are quite aerodynamic. However, the profile of the bullet is not. Shooting in a crosswind will cause the bullet to impact the target off center from the aiming point. Depending on the distance to the target (time in flight), and the severity of the crosswind, the impact point will vary. However, it is repeatable and predictable. But there is another aspect to this type of long-range shooting that most people do not know about. This same crosswind will also cause the bullet to either rise or fall a small amount, depending on the direction of the crosswind, and the rotational direction and speed imparted on the bullet by the rifling in the barrel. This effect is exactly the same effect that the golf ball sees. And in both cases, it is not easy to predict or calculate.

## Propeller Inflow Turbulence

Up to this point, we have looked at how the propeller acts when it is in a clean airflow, and we have covered turbulent or separated airflows. But we have not examined or looked at what might happen to the propeller or the prop wash if a turbulent inflow was present. Obviously, tractor aircraft, regardless of the number of engines, do not suffer from turbulent propeller inflow. The upstream clutter just isn't there. But, what about turbulence caused up-stream of the propeller in pusher aircraft? Just how much of the prop wash is clean? For a typical pusher gyro, with all of the up-stream "stuff" like the pilot, engine, fuel tank, etc., there is a great deal of turbulence, and that turbulence doesn't just go away once it hits the prop. Granted, there aren't large dead spots in the prop wash where there is "shadowing" taking place, but there will be a reduction of flow in spots. This is probably the single toughest factor to include in this equation. Short of having your own private wind tunnel, there is no way to accurately calculate or predict this (<http://naca.larc.nasa.gov/reports/1934/naca-report-448/>). And measuring the prop wash velocity by placing an airspeed indicator behind the propeller of a tied down gyro surely isn't going to prove anything beyond a static condition.



The turbulence that can be found upstream of the propeller on a typical pusher gyro is more comparable to a car traveling down the road at 50 mph, than that of an airplane in flight (<http://www.gmecca.com/byorc/dtipsaerodynamics.html>, <http://www.nag.com/simulation/Fastflo/Documents/ToolBox/html/node28.htm>). Most everyone has seen the effects of turbulence behind a car or truck. Just look at the how effective "drafting" is when going on a long trip, or in stock car auto racing. I specifically mentioned stock car racing because with open wheel classed race cars (CART, Formula Series, etc.), drafting is not always desirable since they are so aerodynamically dependent on down force, even more so than stock cars.



## Summary

A H-Stab on the centerline of the prop wash is going to have 5 major factors against it; 1) dissymmetry of lift of the H-Stab itself because of the helical flow of the prop wash, 2) dissymmetry of lift of the propeller caused by any pitching moment that the aircraft may encounter, with subsequent dissymmetry of prop wash compounding factor number 1, 3) reduced prop wash due to turbulence caused by up-stream clutter, 4) reduced total

effective prop wash due to the close proximity between the H-Stab and the propeller (pulsing), and 5) the lag time between throttle/engine RPM changes and the forward airspeed of the gyro which is necessary to help straighten the helical flow of the prop wash so as to minimize the problem of a stalled H-Stab.

There is one obvious benefit to having the H-Stab in the centerline of the prop wash. If there is a negative angle of incidence in the H-Stab, there will be a positive pitching moment applied to the airframe as the throttle is increased. To a much lesser degree, and I'm sure with a great deal of debate, another benefit may be that as the H-Stab AOA changes, because of a prop wash angle change caused by an airframe AOA change, the resulting thrust that the propeller produces will be reduced, which may automatically lower the airspeed of the aircraft.

<http://naca.larc.nasa.gov/reports/1932/naca-report-389/>

So the simplified answer to the H-Stab in the prop wash question is this – it does a fairly good job of straightening the prop wash, and if there is a negative angle of incidence in the H-Stab, then there will be a positive airframe pitching moment when throttle is applied. But with everything I talked about in this document, mounting a H-Stab in the center of the prop wash is not justifiable because the final performance characteristics cannot be determined with any degree of accuracy without extensive comparative testing! Mounting a H-Stab on the keel is not affected by any of the previously mentioned factors, except airframe AOA, which is a straight forward, simple, and accurate calculation, which has a predictable outcome. And the only downside is that a keel mounted H-Stab will not imply an immediate pitching moment to the airframe as the throttle is changed, which is beneficial if the gyro in question has any amount of CG-Thrustline offset. Many people speculate that this is a major problem at lower airspeeds, because it results in a lack of down force on the tail. Couple that with a possible high thrustline (higher than the CG) and you have a potential cause for a PPO or bunt over, even through the data in the accident report located on the PRA's website (<http://www.pra.org>) does not bear any evidence of such a condition ever occurring.

## ***Conclusion***

I think the ultimate solution to all of the H-Stab debates is to mount the H-Stab NOT in the center of the propeller thrustline, and NOT right on the keel, but at some point in between, so that 40-60% of the H-Stab span is immersed within the prop wash. This location best reduces the AOA influence imparted by the helical prop wash so that H-Stab stalling and dissymmetry of lift is minimized. It is also the cleanest possible airflow location that still maintains some contact with the prop wash, which is necessary to gain the benefit of throttle induced pitch changes to negate any CG-thrustline offset that may exist, and to provide some degree of high velocity AOA change to the H-Stab during a nose down pitching moment of the aircraft while in flight.