Mike Fiore and Joel Beqin in the 48' **Outerlimits** that took Fiore's life at the LOTO **Shootout** in August 2014.


PHOTO: JAY NICHOLS

# Anatomy of a Blowover

## **Why do tunnel boats blow over?** Our expert explains the aerodynamic balance of go-fast tunnel hulls.

by Jim Russell,
AeroMarine Research


A 20' STV sport tunnel hull blows over at Swannee River, FL, in March 2005.

**Every once in a while,** in the world of extreme powerboat racing, there is a severe accident or crash that raises the question, Why do *they do that?* Sometimes these mishaps result in severe damage, injury and sometimes even fatality, as we saw with the horrific crash of Mike Fiore at the Lake of the Ozarks Shootout in August.

When the worst happens, it is a tragedy, and all of us in the powerboating industry mourn for the drivers, families, crews and friends of those involved. Often the most dramatic of these frightening mishaps is when a boat takes off unpredictably and uncontrollably to the air. It's called the "blowover," and we're left questioning why something like this happens.

The 48' Outerlimits offshore catamaran driven by Joel Begin and throttled by Fiore experienced a massive blowover during a high-speed run on Missouri's Lake of the Ozarks. Fiore, who is the founder of Outerlimits, passed away from injuries sustained in the crash and Begin was seriously injured. My heart goes out to their families as they try to endure the ultimate cost of their loved ones who lived their passion.

Blowover accidents are nothing new. The LOTO crash isn't the first we've had to watch and it undoubtedly won't be the last. It can happen with proven powerboat designs and the most experienced drivers.

In December 2009, two Victory 1 team drivers died when their 36-foot, 140-mph Class 1 catamaran blew over in Dubai, UAE. Jeff Tillman and Bob Morgan perished when their 46-foot, 4x1,200-hp Skater catamaran *Big Thunder* went airborne at 130+ mph at the Key West World Finals in November 2011.

Offshore cats are not the only hulls capable of experiencing these horrific blowover phenomena. Performance vee hulls that use aerodynamic lift are also susceptible to instability and blowover. Hydroplane and tunnel hull designs employ more aerodynamic lift and realize more of the associated benefits—but also accept some potential of instability if pressed to the edge. Hank Hogan survived a dramatic 135-mph blowover crash in his 20-foot STV sport tunnel hull at a Swannee River, FL, shootout in March 2005. Remarkably, Unlimited hydroplane driver Jon Zimmerman walked away from a dramatic blowover accident in his U-9 Red Dot/Spirit of Qatar at the July 2012 Detroit Gold Cup Unlimited hydroplane race.

Formula One tunnel boat drivers Pierre Lundin and Jonas Andersson experienced a dramatic dual blowover crash at the UIM F1 Powerboat Grand Prix of Abu Dhabi in December 2009.

The Unlimited hydroplane U-9 Red Dot/Spirit of Qatar blows over at the Detroit Gold Cup, July 2012.

And blowover accidents are not a modern-day development of high performance powerboating, either. One of the first well-publicized race boat blowovers occurred on Lake Washington in 1955 with the 3-point prop-rider *Slo Mo V*, with driver Lou Fageol surviving the accident. The boat did a complete 360-degree flip and landed right side up.

World Speed Record holder Don Campbell died in January 1967 in a 297 mph blowover crash of his 26-foot, 4,600-bhp, Bluebird K7 outrigger hydroplane during a WSR attempt on Coniston Water, England.

So how does a blowover happen?

There is no definitive way to know exactly how any of these specific incidents occurred or what the root causes were. There are hundreds of things going on in a high-performance powerboat, especially at high speeds. Of course, hull design is always important and sometimes it's a mechanical failure—but it's not always the cause.

The bases for the potential for a tunnel boat to experienc a "blowover" are:

- Outside influences cause forces to get out of balance.
- Tunnel hulls are aerodynamically "unstable."
- Performance boats must run at the knife-edge interfac of water and air.

When taken to speeds near-maximum design capabilities, sometimes just a small change in conditions can trigger the imbalance that initiates a dreaded head-over-heels blowover. The situation is most stressed when the boat is going fast, because changes happen quickly. A trigger can cause undesired results when pushed to the limits of hull design/setup or when operating in wind gusts or boat wakes or abnormal weather conditions–and sometimes these can occur at the same time.

While every boat has its own unique design, the forces and reactions acting on a tunnel boat are similar in all situations. I will explain the physics of how these contribute to the extraordinary performance of a tunnel boat and how it works when things go wrong.

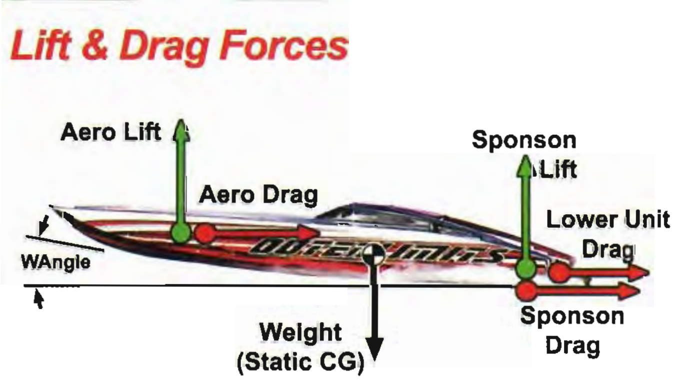
## Boat or Plane?

The offshore catamaran or tunnel hull is like an exotic bird. The tunnel hull derives much of its extraordinary high performance from the aerodynamic lift gained from the "wing" or aerofoil built-in to their design. It also relies on its interaction with the water to maintain a stable and controlled flight. It is really part boat and part airplane.

Tunnel hulls, offshore catamarans and many high-performance hulls are designed to operate with an equilibrium of aerodynamic and hydrodynamic lift and drag forces that must be kept in balance in order to keep upright.

**Design Rule #1**: Balance of Forces—Any boat must generate exactly enough lift to overcome its weight. Not enough lift and the boat sinks – too much lift and the boat takes off like an airplane. This total lift can be produced from hydrodynamic (water) lift or aerodynamic (air) lift, or both. The formula may be noted this way:

**LAero + LWater = Weight**



Any boat must generate exactly enough lift to balance its weight. Not enough lift and the boat sinks; too muc lift and it takes off like an airplane.

Big Thunder Motorsports, a 46' Skater driven by Jeff Tillman and throttled by Bob Morgan, crashed in Key West in 2011. The crash claimed the lives of both men.

In a tunnel boat or catamaran, "water lift" comes from the sponson planing surfaces. Aerodynamic lift is generated by the "ground effect" of the aerofoil (wing section formed by the upper deck and tunnel roof) operating in close proximity to the water surface. These lift forces increase dramatically as the velocity increases. Lift also increases when the angle of attack (trim angle) increases. Thus, more trim angle = more lift.

Any boat must generate exactly enough lift to balance its weight. Not enough lift and the boat sinks; too much lift and it takes off like an airplane.

## Drag is expensive!

With any kind of lift, there comes some drag—it's just an unavoidable law of energy. It is these drags (hydrodynamic and aerodynamic) that limit how fast a boat will go and how efficient it will operate. So designers want to minimize "total drag."

The cost in horsepower of water-drag is 800 times more than that the cost of air-drag, so high performance hull designs try to reduce the need for water-lift and its associated drag by incorporating aerodynamic (air) lift into the hull design.

At 150-mph an offshore racing cat can generate 20% to 30% (or more) of its total weight by aerodynamic lift surfaces. Smaller tunnels, like F1 circuit racing tunnels can generate 60%+ of their lift aerodynamically. It's this high amount of aero lift that contributes to the hulls' fantastic performance...but it also makes it susceptible to dramatic changes to conditions. Aerodynamic lift is generated by the "ground effect" of the wing section formed by the upper deck and tunnel.

## Dynamic Balance

Remember that the boat must always have exactly the amount of lift to balance its weight. This balance of forces means we're considering all of the aerodynamic lift and drag (from tunnel, decks, wing, cockpit configuration, engine cowl, etc.) and all of the hydrodynamic lift and drag (from sponsons, lower unit, propeller, etc.) and the thrust components of the drive system.

More importantly, we need to think of these forces dynamically, which means we're considering all of the forces as they act differently at every discrete velocity throughout the operating range of the boat. For example, there is more aero lift (and less water lift) at 150 mph than there is at 100 mph–and this constantly changes the dynamic balance of the hull.

The location of aerodynamic lift occurs at the "aerodynamic center" of the aerofoil, approximately 1/3 distance from the leading edge. The location of the hydrodynamic lift changes with velocity, depending on how much of the sponson length is wetted–this can be located at amidships at slower speeds or only a few inches at the transom at high speed.

When we consider the amount of each component of lift and drag, together with its location on the hull, we get an overall "center of dynamic balance" (or XCGDynamic) that changes with speed. This "moving around" of the center of water lift, center of aero lift and XCGDynamic makes it tricky to keep the boat in balance, and the experienced driver must adjust throt-

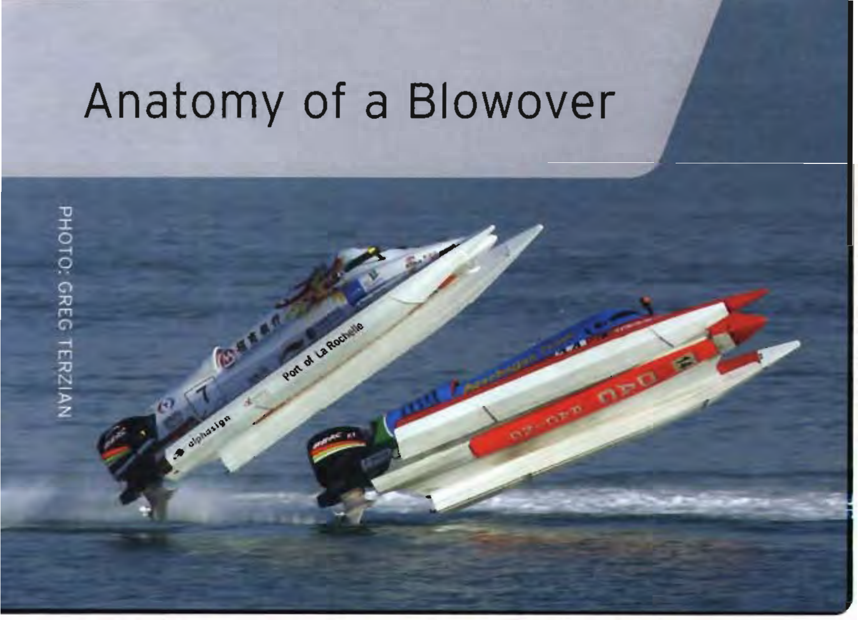


PHOTO: GREG TERZIAN

Formula One tunnel boats blow over at the UIM F1 Powerboat Grand Prix of Abu Dhabi in December 2009.

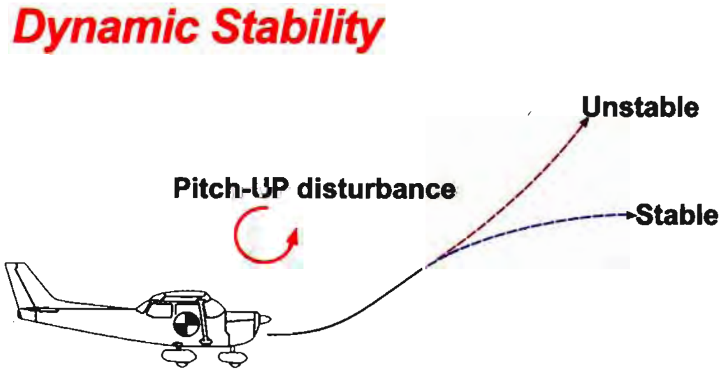
tles, trim angles, etc., to keep the total lift equal to the hull weight (LAero + LWater = Weight).

If the amount of aero lift or water lift changes due to a wind gust, a wake bump, a sponson skip, driver trim change, even a wind direction change or water current change, the force balance is upset, and the driver must make corrections to get things back into balance again.

For example, consider a 46' offshore catamaran at a stable speed of 150 mph, generating just the right amount of total lift (LAero + LWater = Weight). A wind gust of 5 mph can instantly create an additional 300 lbs. of aerodynamic lift. So we are *no longer* in balance–we have *too much* lift! This means that without some kind of instantaneous action, the hull will be airborne.

## Aerodynamic Stability

**Design Rule #2:** From aerodynamic theory... "For a vehicle in "level flight" to be longitudinally stable, a small increase in angle of attack should cause a "pitching moment" so that the angle of attack tends to decrease again. Similarly, a small decrease in angle of attack will cause a pitching moment so that the angle of attack tends to increases again." [Note: A moment is the tendency of a force to produce rotation about a point (CofG) and is equal to a force multiplied by a distance or length.]



An airplane is aerodynamically stable. A disturbance causing a nose-up rotation results in increased tail lift that causes the airplane to rotate nose-down, self-correcting the disturbance.

Here's what this means to powerboat design: Any vehicle in flight, such as an airplane or a high performance powerboat, will experience minor changes to the forces that act on it, and to its speed. If such a change tends to restore the vehicle to its original speed and orientation, then the vehicle is said to be "inherently stable." If such a change tends to drive the vehicle away from its original speed and orientation, the vehicle is said to be "inherently unstable."

An airplane is aerodynamically "stable."

A disturbance causing a nose-up rotation results in increased tail lift that causes the airplane to rotate nose down, self-correcting the disturbance. Conversely, a tunnel boat design is "inherently unstable," aerodynamically speaking. An airplane can be designed to be inherently stable. A tunnel hull cannot be inherently stable, and here's why: When an airplane is properly trimmed in level flight, if it experiences a disturbance that causes a nose-up rotation about it's CG, this causes the tail wing surface to increase its angle of attack and thus increase the lift it generates. This in turn causes the tail to raise up and the airplane to rotate nose down about its CG. It's "self-correcting" to such disturbances.

The airplane can do this because it's designed to have its main lifting surfaces (wings) located right at its CofG, and it's tail section located aft of its CofG, so that the resulting moment caused by increased tail lift is nose-down. These design capabilities make the airplane "inherently stable."

Let's consider what happens when a tunnel hull experiences a similar "disturbance" that causes a "nose-up" rotation about its CofG. The increase in angle of attack causes an increase in aerodynamic lift, which causes the boat to rotate "nose-up" about its CofG. A small increase in angle of attack tends to cause a bigger increase in angle of attack, rather than tending to "restore" things to the original state. This means the tunnel hull is "inherently unstable."

To be aerodynamically "inherently stable", the tunnel boat would have to have it's CofG ahead of the aerodynamic center (AC), so that an increase in angle of attack (Wangle) would cause an increase in LAero and a "nose-down" reaction.

It's difficult to design a tunnel boat to meet Design Rule #2: The heaviest part of the boat's weight (the engine) is necessarily located far aft in the boat where it's needed to drive the propeller. This makes the CofG of the boat almost ALWAYS aft of the aerodynamic center of lift. So an increase in aero lift for any reason, causes a further nose-up condition. This is usually bad for a boat.

A boat doesn't have a second aerodynamic lifting surface (like an airplane's tail) aft of its CofG to help "self-correct" dynamic stability. What's more, if it did, the resulting lift would be lifting the aft of boat OFF the water—this is also bad for a boat!

The tunnel boat has more than just aero lift, has hydrodynamic lift too, and relies on this for control. If we lose this contact with the water, the driver has zero control of speed or trim angle (angle of attack) or direction.

So, if a tunnel boat experiences a disturbance that causes a nose-up motion, the result is more lift that causes *more* nose-up motion, which causes more lift causing more nose-up. In this condition of dynamic instability even small changes tend to cause bigger changes. We are now in the region of easy blowover.

Performance boats must run at the knife-edge interface of water and air. A tunnel boat gets its performance from its use of aerodynamic lift. It maintains its thrust (propeller) and control (steering, trim, etc.) by contact with the water surface. The performance boat must make most efficient use of aerodynamic lift while never losing contact with the water surface.

When a inherently stable airplane experiences a wind gust that causes nose-up and increased lift, it gains a little altitude and inherently rotates nose-down to restore itself to level flight orientation.

Consider a tunnel hull under similar circumstances. Let's pretend that we *could* (which we can't) design the tunnel hull to behave "just like an airplane" so it inherently tries to restore itself to its original level flight orientation by use of lift surfaces aft of CofG. The tunnel hull can't tolerate the resulting "gain of a little altitude" because this alone would lift the boat off the water surface, making it airborne and without control...blowover!

Sometimes these boats fly high, twisting and turning. When a disturbance triggers a blowover and the hull takes to the air, it is now completely unstable and can take almost any path. Initially the boat may rotate around the prop, but as soon as the prop is out of the water, the boat rotates around the center of gravity. This is why some boats hang with the nose up for a short period of time, then quickly do some type of loop, somersault or roll.

## Can Blowover Be Prevented?

There are hull design practices that can make a hull behave better more predictably than others. But since we can't change the basic laws of physics and aerodynamics, we've seen that the performance tunnel boat can always have the potential to react to disturbances as it does now. When a performance catamaran is operating at high speed, at its outer envelope of design, any outside disturbance can trigger a blowover. Once the sequence has started (lift is greater than weight) and the boat control surfaces lose contact with the water, there is simply nothing that the driver can do to get things back into control.

Design alternatives have been tried. Application of canard wings, rear wings, air dumps, water or air brakes are examples of design applications that alter aerodynamic lift and drag but must be 'activated' before the sequence of instability begins. Even with computer-aided "flight" sensing and control of lifting surfaces, once a hull is close to its design performance design limits (lift = weight) any disturbance or change will cause instantaneous instability and the ultimate outcome. We would need systems that "read" what's coming to the boat far down the course, to make the adjustments in time to prevent a problem. So far, only the driver can do that today.

Of course, the best performance analysis and design practices that account for all of the aerodynamic and hydrodynamic forces and hull dynamic stability behavior are important when designing high-performance powerboats.

While it's not realistic to ask professional boat racers to hold back the pursuit for the "edge," as recreational performance boat drivers it's prudent to avoid pushing your boat to the boundary of its design intentions. We shouldn't over-power a hull that was designed for less HP, and we shouldn't drive at outer envelope of design–this is when unpredictable disturbances can trigger instability and undesirable hull behavior.

To protect our drivers of super-fast, high performance boats, our best actions are the design and regulation of high-strength, energy absorbing, safety capsules and under-water survival equipment. The risks of blowover may still be there, so protection is a prudent objective.

## Conclusion

Through the magic of engineering analysis, it is very possible to determine how the boat will react in most all conditions. When performance hulls are operated within their design intentions, reactions and behavior to influencing factors are predictable. At moderate speeds, the needed corrections can become "second nature" for the experienced driver. But at very high speeds, changes happen very quickly, and influencing factors can cause abrupt, rapid changes and instability can get out of control before the needed corrections can be made–and a problem can result—blowover. SB

Jim Russell is a professional engineer with a mechanical and aeronautics background. His published works and papers are highly acclaimed, and are specifically related to the aerodynamics and hydrodynamics of high performance catamarans and tunnel boats, vee and vee-pad hulls. Russell has designed and built many tunnel and performance boats. He has appeared on SpeedVision's 'Powerboat Television' as a guest expert on 'Tunnel Hulls', was performance/design technical consultant on National Geographic's 'Thrill Zone' TV show, and editorial consultant on Discovery Channel's 'What Happened Next' TV show. Russell is the author of the books "Secrets of Tunnel Boat Design," "The Wing in Ground Effect - Their relation to Powerboats," and "Secrets of Propeller Design."

Get your fully illustrated, 13th edition copy of the "***Secrets of Tunnel Boat Design***" book, with over 200 pages of design practices and formulae and over 150 photographs.

The publications "History of Tunnel Boat Design" book, "Secrets of Propeller Design " book, the "Tunnel Boat Design Program©" software, and the "PropWorks2" software for speed prediction and propeller selection are available at the AeroMarine Research web site. http://www.aeromarineresearch.com

"Secrets of Tunnel Boat Design©" book – http://www.aeromarineresearch.com/stbd2.html

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"Tunnel Boat Design Program© ", V7 software - http://www.aeromarineresearch.com/tbdp6.html

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## ***About AeroMarine Research – Jim Russell bio:***

Jim Russell is a professional engineer with a mechanical and aeronautics background. Currently living in Canada, he has done extensive aerodynamic research at University of Michigan, OH and University of Toronto, Canada and marine research at the NRC water channel laboratory in Ottawa, Canada. His published works and papers are highly acclaimed, and are specifically related to the aerodynamics and hydrodynamics of high performance catamarans and tunnel boats, vee and vee-pad hulls. Russell has designed and built many tunnel and performance boats. As a professional race driver, he piloted tunnel boats to Canadian and North American championships. He has written power boating articles for many worldwide performance magazines and has covered UIM and APBA powerboat races. He has appeared on SpeedVision's '*Powerboat Television'* as a guest expert on 'Tunnel Hulls', was performance/design technical consultant on National Geographic's '*Thrill Zone*' TV show, and editorial consultant on Discovery Channel's '*What Happened Next*' TV show. Russell is the author of the "Secrets of Tunnel Boat Design©" book, "The Wing in Ground Effect - Their relation to Powerboats©", book, and the "Secrets of Propeller Design©" book. His company has designed and published the well-known powerboat design software, "Tunnel Boat Design Program©" and "Vee Boat Design Program©" specifically for the design and performance analysis of tunnel boats, powered catamarans, performance Vee and Vee-Pad hulls.