Airboat Engine Power, Reduction Unit & Propeller Dynamics

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Several recent car engine airboat propeller/propeller speed reduction unit (PSRU) failures including at least two brands of propellers and two brands of PSRUs have caused me to seek answers to why long proven propeller brands and models and long proven PSRUs in working combinations have failed without obvious reasons. Reasons for example such as foreign object damage (FOD), like a large object "going through the spinning propeller.

The conditions in common in these failures were; Large airboats, over 500 HP engines, failure at less than 75% of engine power and prop RPM, large wide blade heavy propeller sets, that had operated at full power and RPM many times prier to failure, had many hours of previous operation in varied conditions, and were driven by mature and capable airboat operators.

While the focus of this summary of power and propeller dynamics is about airboats, the related information is taken largely from information about airplane engines, propellers and airplane propeller speed reduction units (PSRU) found by searching the internet for previously developed computations and reports. Any airboater interested lay person or professional engineer could readily find the same or similar information. The physics of motion and forces are common and applicable as well to airboats.

The long standing process of assembling an airboat has taken the course of an individual person or airboat manufacturing company purchasing and assembling the many component pieces of a typical airboat. For instance an engine from one source, a PSRU from another, hull from a source or fabricated by the builder, cage work and engine stand from a source or fabricated by the builder, and a propeller from one of several propeller manufacturers. The source companies of the component pieces have had little input on the combined interactions of the completed product, the airboat.

Many thousands of airboats have been produced in past years with increasing degrees of sophistication. Recently more dramatic increases in basic engine horsepower, airboat size and weight, larger and stronger reduction units, (both belt and gear types) and finally larger and heaver propellers have been produced by several propeller companies. The airboat industry has easily been lulled into not realizing the resulting impact of kinetic energy mathematically increasing exponentially with the units. This applies to weight, RPM of crankshafts, reduction unit components and the propeller, gyroscopic motions, and airboat forward speed. Higher horsepower engines provide more input energy that is large and is accumulated as kinetic energy stored by the moving parts themselves and are cumulative into the entire airboat while in motion.

Centrifugal forces generated with a large wide blade composite propeller turning at say 2100 RPM can range up to 25,000 pounds of outward force on the blade shank and hub. Gyroscopic forces generated by the propeller and imputed by rapid maneuvers, snap turns, bucking water waves and chop, hitting a partially submerged object, etc., can create side load forces in the range of 10,000 foot pounds on the rear bearing of the reduction unit. This five or so foot tons of torque can be up or down or left or right or any combination depending on the direction the bow of the boat is rapidly moved. An engine, reduction unit and the attached propeller set are an inline ridged combination when installed in an airboat. These huge forces are transmitted throughout the entire assembly. The assembly and these forces are held in place in the airboat by the engine mounts and their flexible bushings.

Softer and larger engine mount bushings (sometimes rubber) have been used to minimize the engine and drive component vibrations into the airboat through the engine mount stand and to soften and protect the engine drive combination from sharp movement of the boat hull such as when running dry ground. As described later in this summary, these soft engine mounts, lacking required STIFFNESS, can explain the otherwise unexplained recent car engine airboat failures. These softer engine mounts are generally located at the bottom and rear of an installed PSRU. They are an integral part of the engine, reduction unit and propeller assembly. This combined engine/PSRU/propeller/engine mount system will have an overall natural vibration frequency (or harmonic) contained within the limits of movement allowed for in the engine mount system.

In the operation of an airboat, if the power and RPM of the engine/PSRU/prop should linger at a rate such that an imparted gyroscopic moment induced by turbulence to the boat, (bumps on dry ground, rapid turns, of say wave chop) matches this harmonic and meanwhile be further excited by gyroscopic forces induced by airboat centerline deflection, a condition known in aeronautics as "Whirl Mode" can begin about the center of support of the engine mounts. This harmonic is most often found well below the maximum power and RPM of the engine/PSRU/propeller assembly. Whirl Mode rarely develops because input conditions must be sustained for a brief time period at the required power input RPM to match the assembly's natural harmonic with simultaneously induced gyroscopic force excitation (say a rapid turn) for it to begin.

An excellent, comprehensive and easily understood article describing Whirl Mode can be seen on the EPI, Inc. website at; http://www.epi-eng.com/CNV-WhirlMode.htm

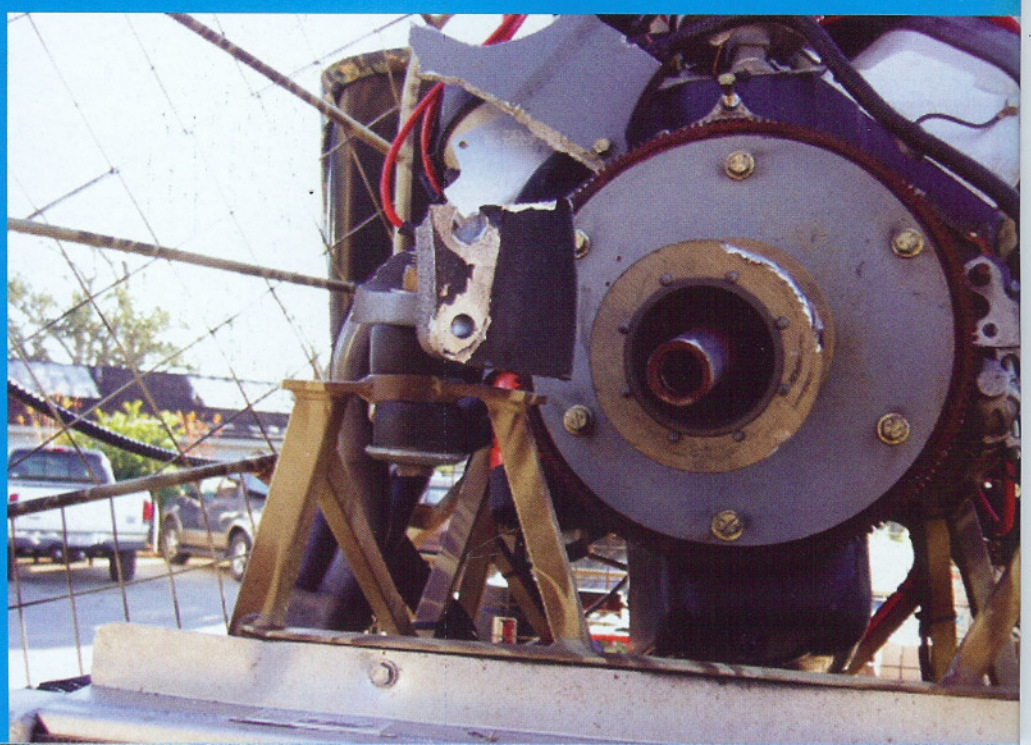
Every concerned airboater should visit this webpage and carefully read it. If you have a car engine airboat with insufficiently STIFF engine mounts, it could happen to you.

Even if whirl mode is induced, sufficiently STIFF and strong engine mounts will hold the assembly within a tolerable safe whirl diameter of movement until an increased or decreased RPM moves the assembly out of phase of the natural harmonic state and the whirl mode subsides. An operator might feel nothing more than a slight momentary vibration something like a "shudder". I think that we have all felt such an unexplained vibration shudder and moved on.

If the engine mounts are soft and of insufficient STIFFNESS, the deflections can develop into a whirling deflection of the engine structure about the center of support of the engine mounts of increasing amplitude until something breaks. As the diameter of this whirl motion at the engine mounts increases, it exacerbates the rapidly reversing gyroscopic forces from the propeller rotation which further takes the propeller center of rotation back and forth around and across the normal rotation center moving quickly into chaotic forces that can dislodge reduction units from the engine, destroy otherwise good propellers and in a fraction of a second, destroy the rear end of an airboat. Because the rotating propeller contains most of the above mentioned kinetic forces and makes the most noise at the failure of this combined assembly, it is natural for a person present at the startling event to jump to the belief that "the propeller exploded". Well I suppose he or she would be partially correct with no concept as to why?

PSRUs of both belt and gear box types are used as a part of this combined engine/PSRU/prop/engine mount assembly. They require right hand rotation propellers for the gear types and left hand rotation propellers for belt drives. The belt drive type of PSRU by nature of its design locates the spinning propeller at least 7 inches further rearward of the engine mounts and the rear of the engine cast iron block attachment plane than does a typical gear box PSRU.

The gyroscopic forces from the spinning propeller that excite and then expand such a developing whirl mode at the rear engine mounts then have a longer force moment with a typical belt drive unit than with a typical gear box. The fulcrum points for these forces are the distance from the front engine mounts to the rear mounts and then on out to the center of the spinning propeller. It is reasonable to believe that this longer moment (resulting in larger forces at the rear engine mounts) may be why there have been more previously unexplained failures of belt drive combinations than of gear box combinations.



Tens of thousands of hollow composite, pitch adjustable propeller blades manufactured by several companies have been operating for more than ten years safely and efficiently. Wood propellers have been around even longer. What is different now? Perhaps some unexplained failures have always been there. Why more now? I submit that larger engines, larger propellers and most importantly, larger and softer engine mount bushings are the reason.

I also submit that more than 500 HP engines, larger reduction units with larger propellers hung on them and all attached to 3/8 inch wide cast iron block webs with the 3/8 inch bolt pattern designed to hold automotive transmissions in cars are near or have reached a limit of design strength for airboat applications. It is also reasonable to believe that possible several foot ton gyroscopic forces and potential "Whirl Mode" effects are alarmingly starting to produce random failures of airboat propulsion assemblies. Any reasonable person could believe that a limit to this 50 year old bolt pattern originally designed for less than 300 HP engines and then only for automobile transmission attachment use where the torque load is directed on through the transmission to the drive shaft with little or no gyroscopic loads would some day reach a horsepower and propeller weight limit for airboat use. Airboat uses impose all the above forces to this attach plane and bolt pattern. Think about it.What to do?

I suggest that car engine airboat owners, check your engine mounts for strength and STIFFNESS", and see your manufacturer if in doubt. Your boat might depend on it. Also check to be sure that the 3/8 inch reduction unit attachment bolts are of the proper grade and length to take full advantage of all of the strength provided in the cast iron engine attachment web. (I suggest that the bolts should be long enough to use all of the available threads before bottoming out.)

The information and concepts that my research has thus far isolated on these subjects have made me realize that the solution to the prevention of future airboat failures of this type is an airboat industry question. I believe that no individual builder, manufacturer of airboats, or product supplier to the

development of airboats has demonstrated anything other than the best of work and intentions in the creation of airboats. However, all of these components, assembled and working together, become airboats in the shops of the airboat manufacturing companies, or in the home shops of individual builders.

With the airboats recently produced having reached the current levels of size, horsepower, boat weight and propeller weight, I submit that it is now urgent to have at least the working engine/PSRU/propeller/engine mount as combined into one working assembly studied and professionally engineered so as to work as a safe and productive unit in existing or future airboats.

Perhaps one or several of the various airboat manufacturing companies working independently or together with other interested parties, that are responsible for the overall assembly of the component parts of airboats, should take the immediate lead in developing answers to these mechanical force questions. I suggest the process would involve the engagement of a well known and qualified mechanical/aeronautical engineering company having state registered engineers in the state in which they practice. Such a company should be formally engaged to develop a complete analysis and computation of the forces involved in various combinations of engine/PSRU/propeller/engine mount assemblies operating in an airboat.

For "car motor" airboat use the general question of the strength of the typical GM 3/8 inch wide cast iron engine block web attachment plane and 3/8 inch bolt pattern should be analyzed and shown to be adequate for reduction unit attachment considering all of the anticipated gyroscopic and mechanical forces applied to it particularly in current large HP airboat applications. Engine mount systems should be analyzed with specific recommendations for the types and stiffness of cushioning bushings. Procedures and directions should be included and described so as to assure that any "Whirl Mode" reaction could never go destructively chaotic. (These concerns have been addressed in aircraft applications of engine/PSRU/propeller/engine mount assemblies and have been the source of much of the information in this summary)

Water Walker LLC has acquired the production rights to the styles of propellers previously produced by the old Power Shift Production, Inc. Should such professional engineering efforts be undertaken by any or all of the manufacturing companies or individuals that assemble and build airboats, Water Walker LLC and its staff pledge to be supportive in furnishing information such as this summary of technical information and such other help as may be helpful.