PROPELLER SYSTEMS

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One of the key ways an investigator has to determine if an aircraft engine was producing power at the time of impact is through a thorough analysis of the propeller system after impact.

The clues here are significant even though secondary by definition to a teardown of the actual engine. Very often, especially in single engine aircraft accidents it is the propeller that impacts the ground first. It then may be the propeller shaft that records first impact and sudden stoppage data. This is because the nose of the airplane is the first at the scene of the sudden stop.

Propellers come in three general variants.

A. Fixed pitch.
B. Variable pitch, positive thrust.
C. Fully variable pitch from feather to reverse.

A. A fixed pitch propeller is the oldest and simplest variety. It is also the least efficient for production of thrust through the various conditions of usage. These are on old airplanes and the least sophisticated. The original were the old wooden carved props. Today they are metal.

b. A variable pitch propeller, positive thrust propeller utilizes a system of rotating blades that can take larger or smaller bites of air. This is dependent upon the blade angle to the relative wind. These propeller systems are governed to operate at a constant speed, and the blade angles adjust to provide more or less power at that speed dependent on engine power being produced. Assume the propeller is being governed to maintain 1,800 R.P.M. at normal cruise power setting and aircraft speed. For the sake of this assumption pretend the blade angle to maintain this condition is 25 degrees of positive blade pitch.

If the pilot adds power the engine wants to speed up and so does the prop. However the propeller is governed to remain at 1,800 R.P.M. Thus the system senses it is expected to do more work and it adjusts the propeller blade angle greater than 25 degrees to scoop and push more air.

The converse is also true. If the pilot reduces power the propeller wants to slow down. Since the governor is forcing it to maintain the selected 1,800 R.P.M it must decrease individual blade angles to scoop or push less air. If an engine fails the propeller will have no driving force except the wind through it. It will continue to rotate and this is called wind milling. In such a case the governor will still try to maintain R.P.M. at the 1,800 level .To accomplish this; the blades angles will decrease dramatically back to a low pitch stop. Normally a propeller of this nature operates between about 20 degrees and 40 degrees. The low pitch stop is set to prevent the prop blades from getting too small or reversing. (Somewhere around 18 degrees)

When an engine fails the propeller that is wind milling at the new flattened blade angle is creating great amounts of undesirable aerodynamic drag. This is a force due to wind resistance. Surprisingly the drag created by a wind milling propeller is almost the same as that that would be caused dragging a parachute with the same diameter throat as the diameter of the propeller. This drag is unacceptable and must be removed. This is done in the next variety of propeller system described.

The Full feathering and Reversing - Constant Speed Propeller

C. A fully variable pitch from feather to reverse is used on large aircraft. This variant of propeller adds two slight changes by increasing the potential blade angle movement all the way from 90 degrees. (Streamlined straight into the wind) to a minus 20 degrees reverse propeller.

When the propeller is placed in the feather position the blades are driven to leading edge straight into the wind. The propeller stops wind milling and the propeller stops dead. Drag is almost completely removed. Some model propeller systems will automatically feather upon loss of engine power, or oil pressure.

The normal operating area remains about 20 to 40 degrees. The low pitch stop for airborne operation is still about 18 degrees. A new area of prop operation is allowed for ground operation. This is called the Beta range. In this area set at about 20 down to zero degrees there is much less thrust produced. It is a good taxi range to save brake overheating in long ground taxi.

Propeller thrust reversal is accomplished by forcing the propeller to fix a negative blade angle of about twenty degrees.
The prop continues to turn the same way except now the wind is forced in the reverse direction. Reverse is selected by the pilot to help stop on short or slippery runways.

In looking at the many engine types and propeller types it is usual that the larger the engine the larger the prop, and the more blades the prop has. Typical propellers range from two to four blades.

If we assume an 1800 rpm prop speed and a three bladed prop, then 90 blades pass a point every second. If you assume a 4 foot prop blade at 1800 rpm you have a prop tip moving at about 750 feet a minute or 450 nautical miles an hour. Suffice it to say the tip is moving right along. For the sake of illustration assume that the airplane is moving forward at 200kts and descending at 3000 ft per minute when it hits. The prop will have the opportunity to have multiple blade strikes before the dome hits (about 8 blades- realistically 3 or 4)

CLUES DERIVED FROM PROP DAMAGE

Let's examine a fixed blade metal prop first since it is the simplest to analyze. First a caveat- The damage differs with speed of aircraft, speed of propeller and dive angle at impact.

A prop under high power at ground impact that results in engine Stoppage will show some or all of the following clues.

a. Prop tip twisting

b. Prop deformation -bend or breaking opposite direction of rotation

c. Severe prop leading edge damages -nicks and gouges

d. Chord wise scratching

e. Torque damage to the shaft and shearing of mounting bolts

f. Sometimes the prop will have torqued of and be entirely separate.

g. Indications of multiple strikes- all blades involved.

When the prop is not under power:

a. Some of the same indications, but much diminished.

b. Singular prop blade involvement.

c. Prop bent backwards -not opposite rotation

d. Spanwise scratches

Let's now talk about the full feathering and full reversing propeller at ground impact. In this situation the investigator must conduct a much more complete analysis and teardown to make determinations about the condition of this system directly at impact.

Remember in this variety of systems the individual propellers are designed to rotate on their hubs in accordance with governor controlled settings of appropriate blade angle. There is no occasion where one blade angle should be different from the others unless the control linkage had broken thus releasing one blade to wander in pitch angle. Further blade angles determine what the propeller system was doing at impact.

a. (20 to 45) normal power range.
b. (18) low pitch stop - low power.
c. (20 to 0) Beta range -ground operation.
d. (90) Full Feather engine stopped emergency situation.
e. (45 to 90) out of control -didn't feather.

Every propeller control system is different, and the investigator must have the maintenance manual and control drawings for the specific one on the accident aircraft. Hartzell, Hamilton Standard, Doty Rotol and McCauley are all different so it is imperative that you get the correct make and model drawings and operations schematics. Suffice it to say that each system is mechanically linked together and linear movement of the prop hub forward and aft is translated to rotational motion of the prop blades at the individual prop hub.

Simplistically, one system uses a hydraulic oil system that moves a piston rearward. The system is spring loaded forward to the feather condition. Thus if this system losses oil pressure, the spring will safely feather that prop. The pilot sets the control governor for a desired speed and the governor sends required amounts of oil into the dome to overpower the spring and therefore position the piston to the proper setting. Since the piston is connected to linkages that rotate each blade, all blades are subsequently moved to the appropriate blade angle.

Since the system is a mechanical linkage where piston position determines prop angle, a simple measurement of the piston position at impact will translate into an equivalent blade angle commanded.

Since crushing and compacting and other distortions occur during a crash it is not unexpected to see multiple witness marks. It is incumbent upon the investigator to determine which mark occurred first. Then all subsequent are meaningless.

a. As a guideline if multiple marks occur, they will usually occur sequentially. Thus either the first or last mark discerned is usually indicative of position at impact. (Not always true)

b. Score marks that drag and leave tails generally suggest that the first impact occurred upstream of the tail.

When a propeller system hits the ground there is a tendency for the linkages to the individual prop blades to break and free up the blades as the impact continue. Also there is the possibility (in reality the expectation) that as the crash progresses the blades will change blade angle on their hub. Thus if possible it is necessary for the investigator to examine each prop hub for its placement at impact. The investigator must determine which blade struck the ground first, and what its blade angle was at that first strike. (That blade angle strike should correlate with the first witness mark position of the cylinder.)

Since propellers are rotating so quickly it is not unusual to have multiple strikes and even multiple strikes on the same blade. There are two ways an investigator tells what the individual blade angle was at impact. Remember that the individual blade is a female part and the blade hub is a male part. Surrounding this hole and metal insertion there are flat metal parts of both the hub and the prop. Often these parts have serial and part numbers inscribed. At impact there may be a perfect transcription of the numbers to the adjacent part. All one need do is line up the transcription and you get the angle.

More likely is the fact that the male hub insertion will cause an elongation of the hole and an imprint around the prop whole surface directly opposing the sudden stoppage of the prop at the angle it was at impact. This indentation will approximate a crescent moon. If there are two such crescents the blade struck twice. Three equals three. As you dismantle a multiple blade system, if one blade has more marks than others it must have been the first to hit with sufficient force to cause the deformation. This usually is the first blade.

To determine the blade angle at impact you lay a ruler so that the straight edge touches both ends of the crescent moon indentation. You then take a right angle and draw a line through the center of the prop hole at right angles to the line drawn by the ruler. You then take an exemplar prop and mold it at zero degrees. Having done this you place the accident prop in the same mold and fit it to the same zero degrees. Now you can get an accurate direct reading between the line of impact and zero degrees .This reading is blade angle at impact. This variety of examination takes an expert, and sometimes an expert combined with a metallurgist.

This type of analysis is needed when there is a possibility:

a. Of a single blade coming loose within its clamps and rotating.
Inadvertent prop reversal.

b. Of an uncommanded prop reversal.

c. Of a prop runaway and over speed.

d. Of an engine failure to produce power.

e. As an excellent comparison of one engine compared to the others. Usually when they are all the same there is normality, all except for out of fuel or icing.

Blade angles also give an approximation of engine power.