Camshaft Lift and Duration Theory

QUESTION:
Could someone please explain what the advantage to having short duration like my 270 over say 320 would be? or the advantage a 320 would have over a 270?

ANSWER / EXPLANATION:
One would think that the ideal camshaft would have 180 degrees of duration and zero degrees of overlap. That is, the intake would open precisely at TDC, close at TDC, and cycle through the compression and power strokes until you were at BDC again, where the exhaust valve would open for another 180 degrees until you reached TDC at the beginning of the intake stroke. Some have even commented that the ideal valvetrain would open the intake valves instantaneously at TDC, leave them open for 180 degrees, and then slam them closed instantaneously at BDC (likewise for the exhaust valves). This would work fine on an engine up to about 2000 RPM, after which power would be seriously compromised.

The main problem is that air has momentum. Because of this, the intake valve must open before TDC in order to make sure that the valve is open far enough to allow the incoming air/fuel charge in with the least amount of restriction once the piston begins to move downward. Likewise, exhausted gases that leave the combustion chamber create a vacuum behind them that is used to assist the flow of the intake charge into the combustion chamber, hence the need for a certain amount of overlap (ie: when both the intake and exhaust valves are open between the end of the exhaust stroke and the beginning of the intake stroke). This technique is called "scavenging" and is present it properly designed exhaust manifolds as well (which time each exhaust pulse so that each one helps draw the next ordered pulse out of the engine). The opposite is also true... long overlap allows the intake charge to help push the exhaust charge out of the cylinder if it is moving fast enough.

Finally, there is funny physics going on between the crankshaft's circular motion and the piston's linear up & down motion. Around TDC and BDC, the crankshaft can rotate almost 20 degrees in either direction while moving the piston downward very, very little. The piston does not move at a fixed, linear velocity inside the cylinder. Rather, it follows the path of a sin wave (eg: accelerating from TDC to a point exactly halfway down, where it decelerates to a stop at BDC).

It all has to do with a factor called "volumetric efficiency", or "VE". VE is a measurement of how efficient an engine is at drawing in air into the cylinders. A cylinder has a fixed volume while the piston is at BDC, and an engine with a VE of 100% should be able to cram in exactly the same volume of air as the calculated volume of the cylinder. Because of restrictions in the intake, however (primarily the venturis on carburetored engines), most stock engines have a maximum VE of around 80%, while most race engines hover around 95-100%. With the proper cam and/or ram air induction, it is possible to achieve a VE greater than 100%. Forced induction engines (ie: those that use turbos or superchargers) develop VE ratings in excess of 100% the moment they develop boost, with each 14.7 PSI equaling an additional 100%. Simply put, the higher the VE, the more air you can cram into the cylinders, and the more power the engine can make.

A camshaft with a large duration (300+) can allow a normally aspirated engine to get very close to a VE of 100% at high RPMs because the exhausted gases leaving the cylinder help to draw in a larger intake charge. By assisting the incoming air to enter the cylinder you cram more air into the engine, and therefore increase the engine's VE. Port velocities are critical, and velocities increase as engine RPMs increase. A long duration camshaft usually has a power band way up the RPM range (6,000+), and a race motor that sees frequent sustained high RPMs can really make a lot of power with that high VE.

There is a tradeoff, however. A camshaft with a long duration doesn't run well at all at idle or low RPMs. At low RPMs the port velocities aren't nearly as high, and scavenging simply doesn't take place. In fact, since there is a slight vacuum in the intake manifold and a slight pressure in the exhaust manifold at all times, opening the intake valve too soon creates a path of lesser resistance for the exhaust gases. Instead of going out the open exhaust valve, the burned air/fuel charge tries to enter the intake manifold instead (commonly called "reversion" because the air in the manifold near the valve actually reverses direction). What results is normally called "polluting of the fresh intake charge". Burnt exhaust gases mix with the incoming unburned air/fuel charge and dilute it, effectively reducing the amount of fuel and free oxygen entering the cylinder (which means a lowered VE). Any drop in VE means an equal drop in power. With long duration cams running at idle, the result is the typical rough idle that you hear on many hopped up V8s. Some of them won't even idle at all without raising the idle RPMs above what is considered normal (in order to introduce more air/fuel, which increases port velocities, which raises VE).

Intake manifold design (dual plane, single plane, high rise, velocity stacks, etc.) can all contribute to engine tuning as much as header design does. The choice of camshaft defines both. An engine's displacement and camshaft define the style of intake and exhaust manifold used on an engine. Get everything right and you get free power. Get one or two things wrong and you lose power.

Remember way back when I mentioned the theory of instantaneous valve openings and closings? Many people thought that this was an ideal (albeit highly impractical) method of allowing the maximum amount of air in and out. After all, how could a design that allowed the valves to slowly open and close provide any real flow during those periods of low initial lift? Actually, it has been determined that the slow openings and closings are *necessary* for proper engine operation. When the piston begins its downward travel from TDC during the intake stroke, the first few degrees of crankshaft rotation create hardly any downward movement in the piston.

Opening the valve instantaneously at this point would cause port velocities to plummet, causing turbulence in the intake system and cause fuel to drop out of suspension.

Now getting back to your question:

A low duration camshaft works best at lower RPMs. Even though the stock cam has a duration of about 250 degrees, a mild aftermarket cam like the Engle 100 (duration 270 degrees) will still move the point of maximum torque/horsepower further up the RPM range. A cam such as the Engle 100 will idle smoothly and possess good port velocities at low-to-mid RPMs, increasing the engine's VE within that range (a good guess-timate would be a VE of about 85%). Eventually the low overlap of the 100 will hurt the engine at high RPMs because the low overlap does not allow much scavenging to take place. The valves are also open for less time over all, which limits the engine's maximum VE (unless you resort to forced air induction using ducts, turbos, or superchargers).

A super-high duration camshaft like the "320" you mentioned (the closest Engle equivalent being an FK-87) is pretty much an all-out race cam. It works best at very high RPMs where the scavenging effect could conceivably push the VE up beyond 100%. 100% is greater than the 85% of the Engle 100, and potential maximum torque and horsepower are much greater with the FK-87 as a result. The down side is that the FK-87 would idle like a poorly tuned Harley (due to reversion) and have very poor off idle performance (due to low port velocities at low-to-mid RPMs).

Lift is another matter entirely (are you getting tired of reading yet?). Increasing lift has exactly the same effect as increasing the cam's duration, except that you are not actually altering the opening and closing points of the cam lobes. Increasing duration allows more air in & out, and so does increasing your maximum lift (the former increases the size of the valve opening while the latter simply increases the amount of time that opening is open). A lot more goes into determining a cam's maximum lift (or rate of valve opening) than does its lobe timing, though. Maximum lift's main enemies are mechanical in nature, and have to do with a) coil bind and B) valve-to-piston interference.

Coil bind is what you get when you attempt to open a valve so far that the spring that normally holds the valve closed can't compress any further (the coils end up coming in contact with each other until it is nothing else than a solid column of spring steel). Valve-to-piston interference is a no-brainer, since a valve that opens too far stands a good chance of coming in contact with the top of the piston at TDC (the common solution being to machine valve pockets in the piston dome to provide clearance).

That's the easy part. A cam's maximum lift doesn't just determine how far the valves lift off their seats, however. It also determines how *fast* the valve moves off the seat to the point of maximum lift and back down onto the seat again (commonly referred to as "ramp speed"). A high lift, high duration cam lobe is gentler on the valve train than a high lift, low duration cam because the ramp speed isn't as quick. High ramp speeds coupled with weak valve springs can result in a) "ski jumping" just after maximum lift is achieved and B) valve float.

"Ski jumping" occurs when the lifter is accelerated off the tip of the lobe so fast that the lifter actually leaves the surface of the lobe and becomes "airborne". This will affect valve timing-- specifically altering the moment that the valve closes. It also means that the valve will come down on the valve seat harder than normal. "Ski jumping" often occurs at high RPMs without sufficient valve spring tension and when matching high ratio rockers on camshafts designed only for use with the stock 1.1:1 ratio. Valve float happens when the valve isn't placed back on its seat gently enough, causing it to bounce once or twice before the valve spring tension holds it down firmly. This is "A Very Bad Thing"™, as it will pound out seats, break the heads off of valves, and be generally rough on the rest of the valve train components. Maximum lift isn't the sole contributor to ramp speeds, however. The overall silhouette of the lobe is the key.

The camshaft is the heart of an engine, and it influences all the other factors of your engine design. When building a motor, cams are almost always chosen first (sometimes second when you are dealing with an engine who's displacement is easily changed-- like the Type 1 ACVW).

PS: Not all identical model camshafts should be considered equal. It used to be a common practice to "regrind" camshafts. The existing lobes were shrunk in size to compensate for any areas on the original lobe which experienced extensive wear (IOW, modified the original shape of the lobe). Cam lobes contain an area called the "base circle" which is the part of the lobe that the lifter rests against when the valve is fully closed (think of it as the coast side of the lobe). The top of the lobe is what provides the valve train with its maximum lift. Maximum lift is essentially the difference between this point and the lobe's base circle. If you think about it, it is easy to see that you can reshape the existing lobe and create a cam with the same characteristics as it had before, by simply "shrinking" the lobe. As long as the difference between the high point and the base circle is the same as before, total maximum lift has not changed. And as long as the rise and fall ramps of the lobe start in the same degree positions as before, duration hasn't changed either. However, the lifters will sit further out of their bores and you'll have to turn in your valve adjusting screws another turn or so to make up the difference. Likewise, it is conceivable that a camshaft manufacturer created a cam with lobes larger than what your valve train can handle. Stories regarding lifters that bottom out in their bores prior to the cam achieving maximum lift are nothing new. My point? Don't assume that your new camshaft will simply drop in. Measure everything at least three times and if you are ever in doubt, ask someone else.