Goin' with the flow

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DESCRIPTIONS OF HOW CARBURETORS work tell us that fuel spraying from the needle jet is atomized by the airflow and...

Wait. Stop right there. How is it atomized, and why? What makes the atomizing finer or coarser? Let's look into it. Long ago, a fellow named Hochschwender photographed droplets suspended in a rising stream of air. They weren't "teardrops" at all, but were squashed spheres, flattened by air pressure on the side facing the flow. As drops were made bigger, or the air velocity higher, they became flatter until their centers caved in under the pressure of the air streaming against them. Then they popped, reformed into a ring, then burst into a necklace of much smaller droplets.

Why should this be? The grand old man of fluid mechanics, Ludwig Prandtl (1875-1953) outlined the matter. Liquids are held together by molecular forces of attraction. Inside the liquid, these forces are largely "invisible" because they act in all directions, but at the surface, they act like a skin under some slight but measurable tension–the so-called surface tension. In the absence of other forces, surface tension pulls the droplet into spherical shape. Just like the rubber skin on a water balloon, surface tension produces pressure inside the droplet. This is proportional to surface tension, and inversely proportional to droplet size. Opposed to this is the pressure of the air hitting the drop, which tends to flatten it. This is called the dynamic pressure, and is proportional to the density of the air and the square of its velocity. As the flow slows in hitting the droplet, its kinetic energy is converted into pressure energy.

Fuel shoots from a carburetor's needle jet, straight out into the intake stream, which is speeding past at hundreds of feet per second. The fuel droplets are heavier than the air, so they can't instantly accelerate to airflow speed, but lag behind. This difference in speed subjects them to dynamic pressure, which flattens them in good old Hochschwender style, bursts their centers, and explodes them into halos of tiny droplets. If the airflow velocity is high enough, and these smaller droplets have not yet accelerated up to speed, they, too, may in turn be flattened and burst into yet-tinier droplets. In short, Hochschwender and Prandtl proposed that for a given air velocity, there was a corresponding droplet size to which fluid would inevitably be broken down by this process. To estimate what this size might be, Prandtl suggested that a droplet would break when the dynamic pressure of the air equalled the droplet's internal pressure, created by its surface tension.

This gives us part of the reason why smaller carburetors are easier to tune than bigger ones; they produce higher venturi velocity which physically beats the fuel droplets down to smaller sizes. These smaller droplets evaporate promptly to make an easily ignitable mixture that engines thrive on. Engines are often designed to give mean intake-duct velocities near 350 feet per second. Using this velocity, Prandtl's formula gives a droplet size of about 100 microns, or .004 inch. This is not bad for a rough calculation, for in fact droplet sizes from carburetors range between 50 and 200 microns. Why so big? Remember that this calculation is for the case in which the droplet is hit with full stream velocity. In reality, by the time mid-sized droplets have been formed from the break-up of big ones, the air will have accelerated them quite a bit, so the relative droplet-to-air velocity will have fallen. The droplets are coming up to speed in the airflow. That permits some bigger ones to escape unbroken.

Now consider a limiting case. The air-blast fuel-injection system used on Orbital Engine Company's automotive two-stroke engines works as follows: There is a pre-chamber, connected to the engine's combustion chamber by a small orifice. Fuel is injected into the pre-chamber, forming large-ish droplets in the 50-100 micron size range. Next, a tiny valve opens, admitting a burst of air to the pre-chamber at 60 psi. This drives the coarse fuel/air mixture out through the orifice, where the flow reaches the speed of sound, and into the main combustion chamber. Naturally, the air, being lighter than fuel, accelerates quickly through the orifice, leaving the fuel lagging. This produces a very great speed difference between the droplets and the air accelerating past them, and the result is extremely fine atomization–down to a mean droplet size of 10 microns, or .0004 inch. When we try this number in Prandtl's formula, we get a corresponding velocity of 980 feet per second–satisfyingly close to the speed of sound.

There are endless racing and hot-rodding epics in which the hero struggles to get big, hi-po carburetors to work on his modified engine, but just cannot combine all necessary aspects of performance–acceleration, top speed, throttle response, freedom from detonation.

Yet it all makes sense. Tiny fuel droplets from small, high-velocity carbs evaporate fast and ride happily with the air to their hot destiny in the cylinders. Big droplets from monster mixers prefer to resist and misbehave every way they can: wetting the walls, refusing to turn corners, failing to evaporate fully, even splattering against sparkplug insulators where heat bakes them to conductive carbon film that shorts out the spark. The engine misfires–"shoots ducks," in the old hot-rod lingo–and doesn't clear until high rpm brings the intake airspeed up enough for good mixture to resume. Sudden throttle movements leave these liquid sluggos loitering in the intake pipes while the now-lean air/fuel charge hastens to the cylinders.

The unhappy result is a "momentary interruption of service," with detonation–the spice of the tuner's life–a likely possibility.