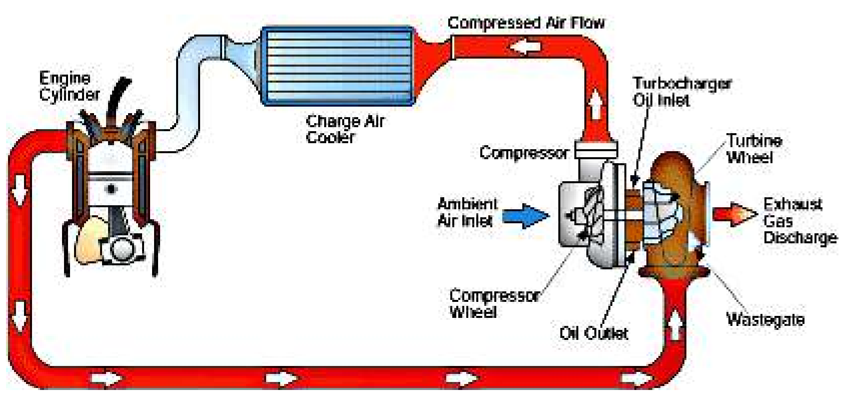
THE VGT EVOLUTION
INDUCTION OVERHEATING-LLY DURAMAX

This became a project for me in 2005 after the LLY Duramax was released. I was asked to consult on an overheat issue plaguing a company's entire fleet of Light Duty GM vehicles. The complaint was that many of the trips would result in overheating problems. Other complaints centered on excess fan activity, poor economy, and perceptively poor power response on grades. I had planned 2 months to resolve it. I did not realize at the time that the problem would be so difficult to pin down. I had to evaluate each mechanism in the vehicle to finally track it down. For me the heat transfer mechanisms were easy to log, easy to track and easy to assemble. The thermodynamic mechanisms, and what would turn out to be hidden flaws, were much more difficult to nail down. I had to reacquaint myself with compression thermodynamics to finally arrive with my finger on a cause, after nearly 2 years, and many painstaking trials.



The changes that brought about LLY overheat, for those that utilize the vehicle in severe work conditions, are

1) The redesign of the intake to accommodate the mandated EGR,

2) the elimination of the wastegate, through adoption of the variable geometry turbocharger, VGT, and

3) the reduction in size of the induction plumbing…CAC boost tubes. It is also important to note

4) the fan coupled IAT rise. While this is not a change for the LLY, it is a critical element that magnifies the effect of 1), 2), and 3). The higher fan drive ratio for the LLY does, to a small degree, impact the magnitude of this IAT rise.

1. Intake Redesign. Far and away the biggest design flaw in forced induction history. I am referring to a very hidden innocuous contorted conduit that acts as a mouthpiece for the compressor. It was redesigned to squeeze into an abnormally small space as a result of the EGR packaging, and the consequence is an enormous amount of pressure drop and turbulence. This causes the compressor to work harder and run outside of the intended rpm range and efficiency, thus producing an extraordinary amount of heat. Normally a wastegate would limit this damage. The elimination of the work limiting wastegate allows an unrestrained thermal condition to develop.

2. Elimination of the Wastegate. By and large, the wastegate has multiple functions. Most people recognize that it limits boost, bypassing exhaust flow when the preset compressor boost limit is reached. That boost is sensed at the compressor discharge where the wastegate line is located. But it does more. For this discussion, the essential feature of the wastegate is its inherent ability to put a hard ceiling on the work performed by the compressor. In a real thermodynamic sense, it limits the heat that the compressor can generate, especially prominent at the redline rpm limit. I will skip compression thermodynamics; accept to state that the turbocharger compressor creates a lot of heat in the charge air (measured up to 590 F). If Inlet Air Temperature, IAT, goes up, then this heat also goes up, increasing by a factor of 150% of the IAT change. This creates higher plumbing velocities and friction losses. The real magic of the wastegate is that as IAT gets hotter, the compressor is moderated to keep from further heating the charge air. Physically, you would see a decrease in intake plenum pressure as IAT increases, while discharge pressure remains pretty much constant. The reason this is, is that the wastegate controller maintains a hard boost limit on the discharge, and this equates to a quasi-limit on heat production.

The VGT cannot do this!

Variable Geometry Turbocharging eliminates the wastegate. It has no boost or heat limit protection, no wastegate, nor even a PCM code to detect and correct this condition. When IAT heats up and begins to heat charge, there is NO MECHANISM to limit work (and heat) produced by the compressor. Where the LB7 boost is controlled to a discharge limit, the LLY boost is controlled at the intake plenum by the MAP sensor. It asks for 20 psi, and if there is 400 mph air charge due to heating and an 8 psi loss in the plumbing, then the discharge pressure, COP (not monitored) is commanded to 28 psi, because that is what's necessary. It's that simple. With this much discharge boost, the compressor is operating off the manufacturers compressor map much of the time, and at higher elevations, all of the time. This means yet more heat due to the lower operating efficiency of higher boost, and a greater likelihood of overheating at elevations.

3. Plumbing sizing. All fluid transport systems must have carefully calculated ductwork to minimize plumbing losses. When dealing with adiabatic compression, it is ultra important. Restriction means extra boost (work) and added heat. GM botched this step also. The LLY emerged with very restrictive boost tubes, undersized for the severe thermal conditions created above; from the LB7's 3" to the new 2.5". This increased charge velocity in the pipes 44-60%, leading to significantly larger air friction losses, between 2 and 3 psi of added restriction. An awful waste of boost, and tragically, significant increases in heat production. So the new heat machine (Variable Geometry Turbo), sends the resultant heat product to the CAC, where, with its added heat load, rejects much more heat into the ambient stream, firebombing the radiator in effect, with ambient heated to as much as 240 degrees.

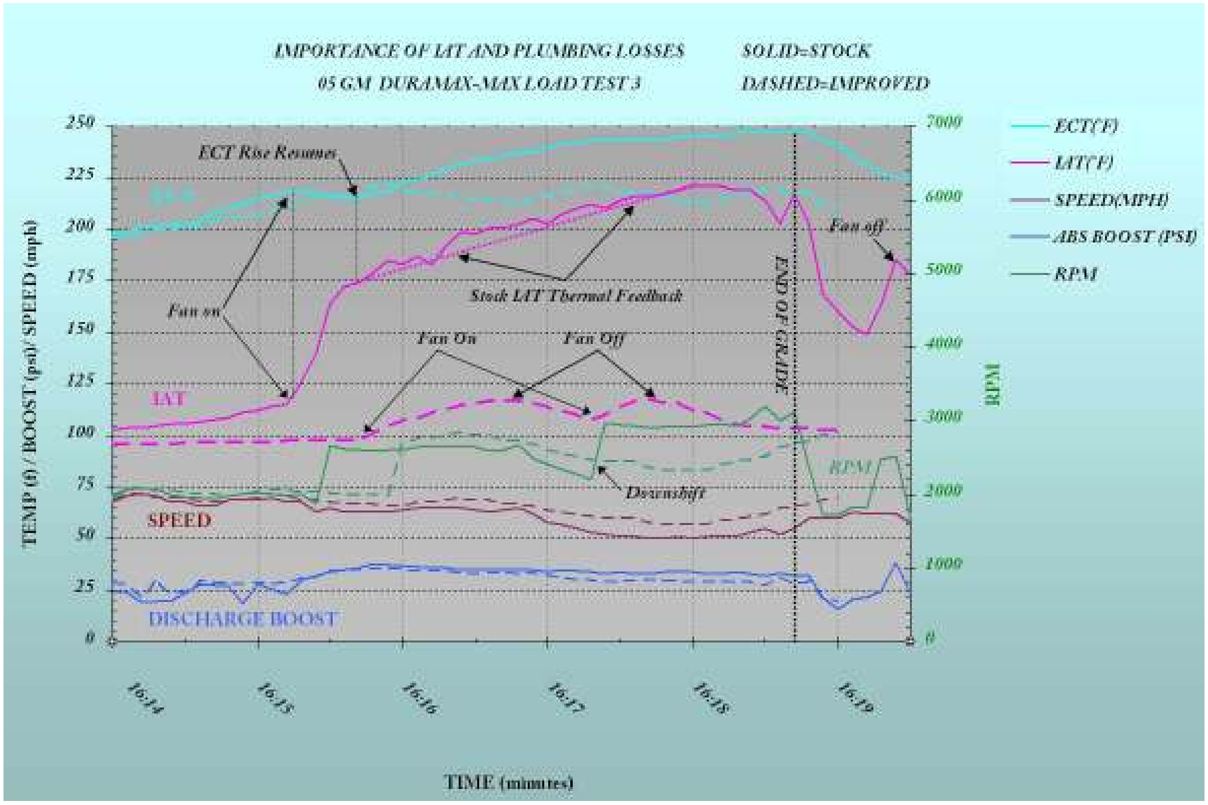
The radiator has plenty of potential capacity, when it receives the intended cool air. The problem is what happens upstream of the radiator…at the CAC. The CAC overheats first, and the product heat cooks the radiator.

With EFILive, it is possible to create a software "wastegate". It requires careful boost reduction with increasing IAT and elevation. That is the basic concept.

Anyone can improve the overheat issue by employing a cold air intake, improved intake compressor mouthpiece and larger boost tubes. I have had very good results with this, though I quickly discovered that many of the big name aftermarket intake companies assign the designation "cold air intake" with no real world intake temperature improvements, so buyer beware. Some of them are no better than the stock *hot* air intake.

Now you can mask this issue with cooling system expansion, but you are still left with all the byproducts of poor induction design. The main one is that intake plenum temp (post CAC) can get real high, over 250 degrees, and this leads to significant oxygen loss, over-advanced timing, and ensuing power loss on the grade. The ONLY way to address that is keeping IAT down with the correct CAI, and then helping out the compressor efficiency issue further by using larger, improved plumbing so that the compressor does not have to work so hard. In other words, creating the least restriction possible in the plumbing.

4. IAT Rise. This is the easiest to see for yourself. Just hook up a scan gauge (sold here) or scanner to the OBD port, and watch what happens to IAT. On a hot day at a stop light, it is not uncommon to see 160 degrees. Pull a significant load up an elevated grade, and see what happens when the fan engages. With the new smaller fan pulley, IAT has been observed to go from 110 F to 200 F, in 2 minutes. I have personally logged 243 F on grade. The turbo is designed for 80 degree air, and 243 F represents more than a slight fever to the compressor. The added workload at this temperature represents a serious turbine and compressor overspeed at WOT.



I don't overheat, why should I care?

Fuel economy is in the toilet during these conditions. A 30% mpg improvement is easily possible at WOT, when this mechanism is fixed. A 10% minimum mpg improvement will also be observed at lighter loads. That's money-back at the pumps. Mass Air Flow is increased, permitting the use of lower boost for a given target air density. The fan will also become conspicuously absent all of a sudden. Enjoy the silence. Also, because it has to work less, the turbo rpm is reduced by over 15,000 rpm, and this means lower exhaust backpressure, (more HP to the wheels) and 100-200 degree lower EGT's, not to mention a grateful turbocharger that will outlast your neighbors as you are passing him on the grade. ;-) When power is up, grade speed is up, which is beneficial for cooling as well. These are the kinds of improvements that are a win-win-win. The best part about this is its all passive. ***No Batteries Required***.

To learn more about the science behind these concepts, read the expanded research in Thermal Feedback Primer, and Thermal Feedback Loops in Turbocharger Applications.

Simple Definition
http://members.cox.net/td-eoc/THERMAL%20FEEDBACK-SIMPLE.pdf

Intro to Thermal Feedback and Thermodynamics
http://members.cox.net/td-eoc/INDUCTION-THERMAL%20FEEDBACK%20PRIMER.pdf

Expanded Thermal Feedback Article
http://members.cox.net/td-eoc/THERMAL%20FEEDBACK%20LOOPS%20IN%20TURBOCHARGER%20APPLICATIONS.pdf

Prediction Worksheet for understanding the impacts
http://members.cox.net/beekiller/GMC%20Light%20Duty/Turbo%20Calc%20spreadsheet.xls

Thanks for looking.

Michael Patton, ChemE
Aka Killerbee