CUSTOMPERFORMANCE engineering

MazdaSPEED3 Front Mount Intercooler

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- ***Why do you guys take the time to collect all this data? I've never seen a company go through so much trouble to market a product!***

One unique aspect of Custom Performance Engineering, Inc. is our transparency in testing methods and the posting of the empirical data. One would be hard pressed to find a product on our website that does not have some kind of technical documentation or validation, and we do this for you, our customer. Quality performance parts for these cars are expensive, and we strongly believe that anyone considering purchasing them deserves to know exactly how a given product will perform under real-world conditions. We test our products, and if they do not meet or exceed our expectations then we redesign them, period! We know our products are in a league of their own, and these kind of technical documents are designed to show you exactly why we feel comfortable making such bold statements.

INTRODUCTION:

The SPEED3 is arguably one of the hottest cars that Mazda has produced in many years. One reason why the car has been so successful is because it responds so well to breathing upgrades. An already fantastic sport hatch can be turned into an absolute monster with nothing more then an intake and exhaust upgrade. Few cars in history have responded so well to aftermarket upgrades, and the good news is that things are only getting better…

The intercooler on the SPEED3 is almost identical to the intercooler found in the SPEED6, therefore many of the same rules apply here. (You may read about our SPEED6 intercooler testing **here**). Heat soak is a major issue, thermal efficiency leaves a lot to be desired, and in our opinion the pressure drop across the intercooler core from the factory is criminal. One might construe these issues as being an unsolvable problem, but its good news because the car is going to respond much better to a well-engineered front mount intercooler kit.

Our intercooler upgrade kit features a relatively long horizontal flow bar and plate core. The use of a horizontal flow core is desirable because the opening in the stock SPEED3 bumper cover is perfectly suited for a short and wide horizontal-flow intercooler. Any intercooler core that is blocked by the bumper is not doing its job, and is little more then dead weight.

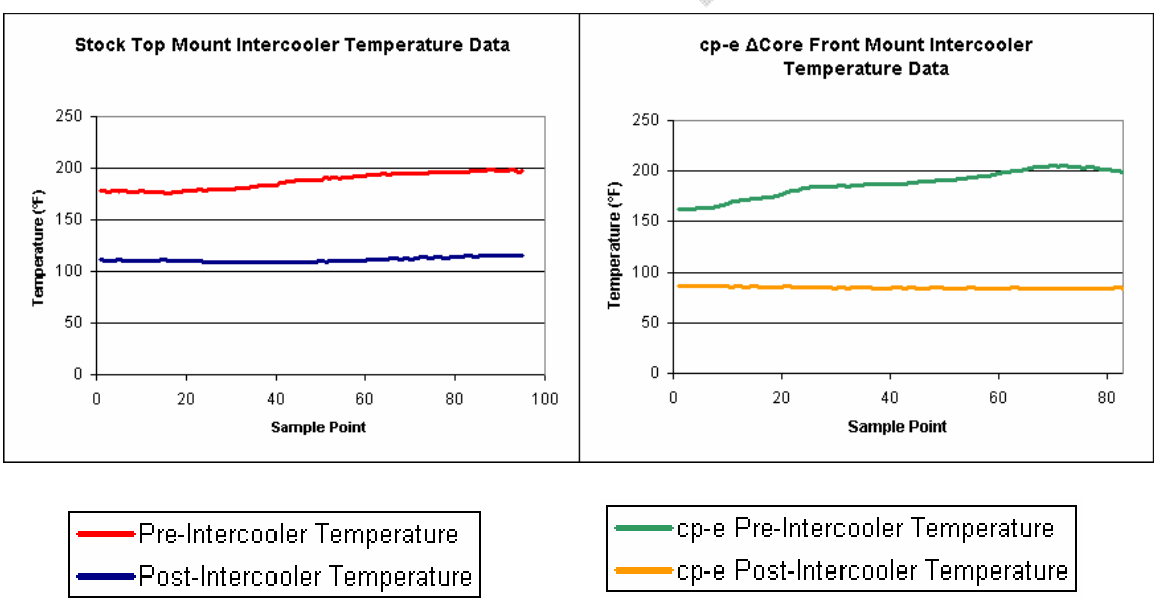
Relatively unique is the choice to use 2.25" aluminum piping with our intercooler kit. Although 2.5" piping is much more common in the aftermarket, it is NOT ideal for a street driven SPEED3. This is because the diameter of the intercooler piping should be based upon how much air the engine will pump, and not the "Bigger is better" adage. Obviously the more air your engine will flow, the larger the diameter pipe you will need. However, a 2.25" pipe is good for ***over* 450hp**, and anything larger for anything less then about 500hp will just create turbo lag. We must stay strong and resist the temptation to believe that bigger is always better!

So, we have talked about how great the design of our intercooler kit is, but talk is cheap…

THERMAL EFFICIENCY:

When shopping for an intercooler, thermal efficiency is paramount among all of the other considerations. The thermal efficiency of the intercooler kit is going to tell you how capable the core is at removing heat from the air charge. In other words, the higher the thermal efficiency, the lower the resulting outlet temperature will be. Since cooler air is **always** better for power production, you are going to want a kit with the highest thermal efficiency possible. However, the trick is to achieve a high thermal efficiency without using an excessive pressure drop as a band-aid. Anyone can install an excessively large intercooler core into their car, but they'll likely suffer from a substantial pressure loss, which translates into a performance penalty. So we must strike a balance between optimal cooling and reasonable pressure loss.

The testing procedure for both the ΔCore™ and stock intercoolers was simple: Using the same test track for each case, the car was brought to operating temperature and the engine output was held at maximum capacity from 1st through 4th gears. The resulting inlet and outlet air temperature, as well as the pressure drop was recorded using our own data logging equipment. We then graphed and analyzed the data.



Ambient air temperature: 57°F **Ambient air temperature: 58°F**

The two charts above are a visual representation of our test data. Immediately noticeable is the extraordinary **120°F** temperature drop achieved by the cp-e™ ΔCore™, but there are other more subtle points worth noting.

(*Note: The total temperature drop for the stock intercooler measured 83°F*).

We can also gather a lot of information about an intercooler if we consider its resulting outlet temperature. Intercoolers are nothing more then heat exchangers. They provide the medium to transfer heat from one fluid (the turbocharger outlet air) to another (ambient air).

Because energy cannot be created or destroyed, that heat has to go *somewhere*, and if an intercooler has reached its heat rejection capacity then the outlet temperature will rise relative to the inlet temperature. If this happens, we can assume that no additional heat is being transferred to the ambient air, and the intercooler has essentially reached its heat rejection capacity.

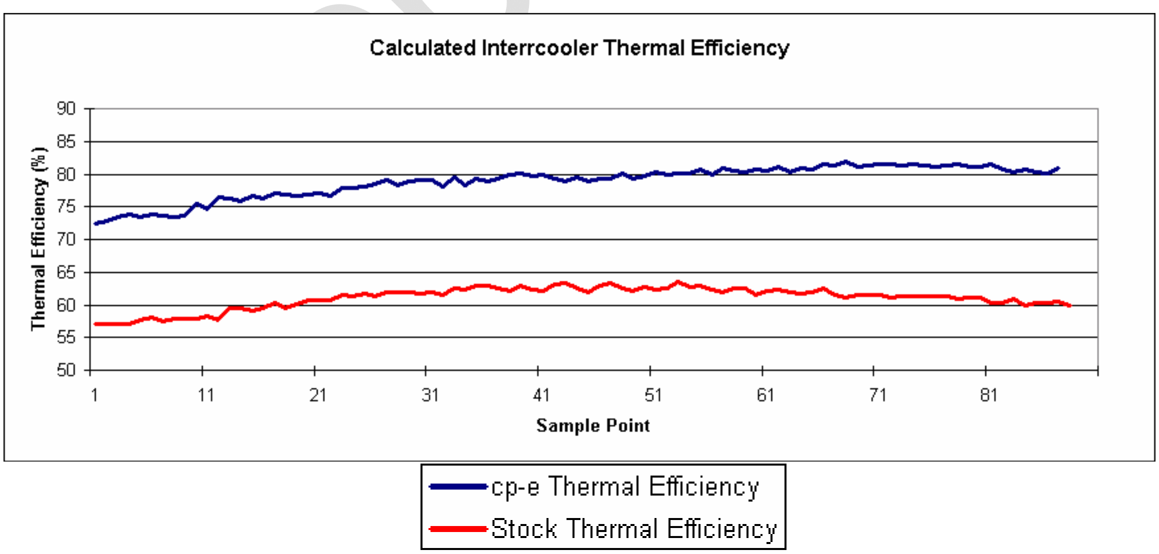
If you look at the stock intercooler outlet temperature, you'll see that it begins to rise towards to the end of the run. Realize that this increase in the outlet temperature is occurring despite the fact that the vehicle is accelerating in speed, which increases airflow across the intercooler. However, when you study the cp-e™ ΔCore™ graph, you'll see that there is a slight *drop* in the intercooler outlet temperature, which indicates that has the intercooler hasn't reached its heat rejection capacity. What does this mean for the end-user? Well, considering that the test SPEED3 was nearly stock (save for an intake and downpipe), we can assume that the stock intercooler is inadequate even in stock form! This typically results in inconsistent performance under varying conditions.

"So what if I want to compare the performance of one intercooler relative to another, but with different ambient conditions? What then?"

Because an intercooler's total temperature drop is greatly influenced by ambient conditions, the intercooler efficiency calculation takes this into account and "levels the playing field," so to speak. The formula for calculating an intercooler's thermal efficiency is as follows:

$$IC_{Eff} = \frac{T_{IN} - T_{OUT}}{T_{IN} - T_{ambient}}$$

Now we can compare the performance of both the stock and cp-e™ intercoolers without the ambient temperature being a variable. So we can see which intercooler was better at rejecting heat even if the testing conditions were not quite identical:



It comes as no surprise that the cp-e™ ΔCore™ intercooler has a higher efficiency then the stock intercooler considering that it managed a higher total temperature drop. A decent intercooler should have a thermal efficiency of about 65%, which the stock intercooler barely falls short of (max efficiency of **63%**). But even we weren't expecting a staggering **82%** thermal efficiency from the cp-e™ ΔCore™! Maybe the best part about that efficiency rating is that unlike the stock intercooler, heat soak is almost negligible so that efficiency rating will not change appreciably when the vehicle comes to a stop. Previous testing showed a 6% decrease in top mounted intercooler efficiency when heat soak is considered:

The following data was recorded on a SPEED6 with the stock top mount intercooler 12/2006:

Normal Start		
Turbocharger Outlet Temperature	167	°F
Intercooler Outlet Temperature	86	°F
Ambient Temperature	41	°F
Efficiency	**64**	%

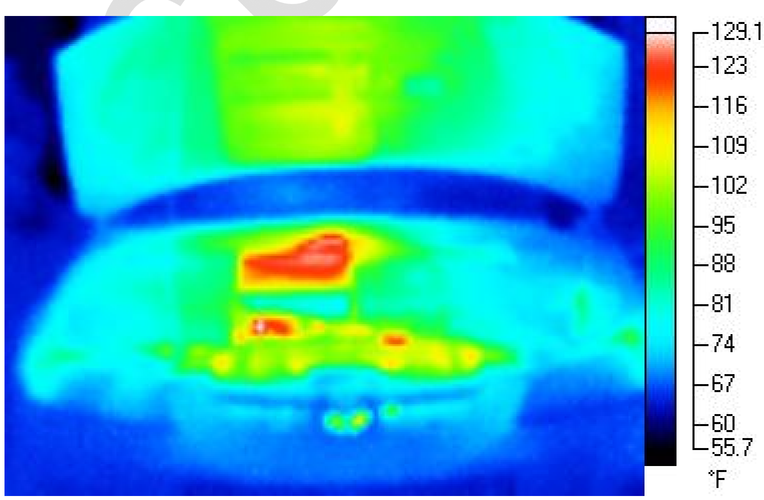
Hot Start		
Turbocharger Outlet Temperature	219	°F
Intercooler Outlet Temperature	132	°F
Ambient Temperature	71	°F
Efficiency	**58**	%

THERMAL IMAGING & HEAT SOAK:

(Note: Due to the similarities between the SPEED6 and SPEED3 intercoolers, the following data was collected using a SPEED6. However, the data is applicable to both vehicles.)

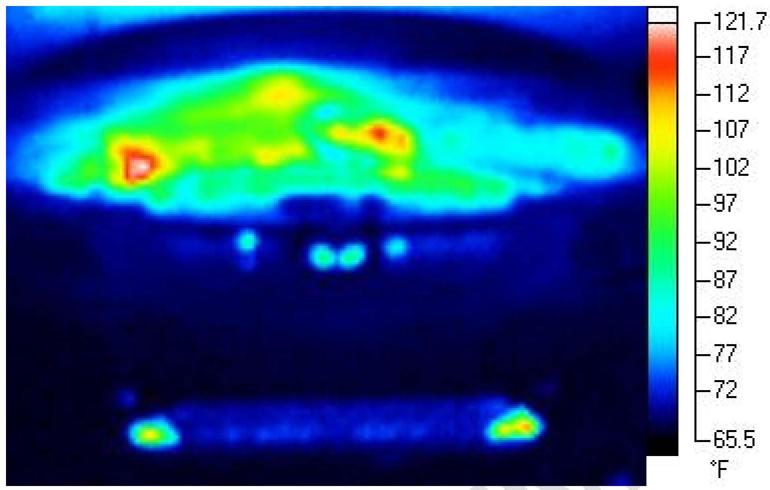
We wanted to illustrate what happens to the stock top mount intercooler when the car is simply at idle. So, the SPEED6's hood was propped open, the car was started, and after it warmed up the thermal imager was used to record the temperature of the entire engine bay. Now, since the turbocharger is not producing any boost, any heat the intercooler receives must be a product of conduction or convection (radiation heat transfer is negligible at these temperatures) from under-hood components.

You can clearly see the red and white shades of the top mount intercooler, which represent a temperature of about **120°F**.



Stock Top Mount Intercooler

Since the cp-e™ intercooler is in front of the car, it will receive very little heat transfer. This is ideal as the intercooler is now only responsible for cooling the intake air, as opposed to waste heat from the engine. You can see the blue rectangle behind the bumper, which indicates a temperature of about **75°F**.



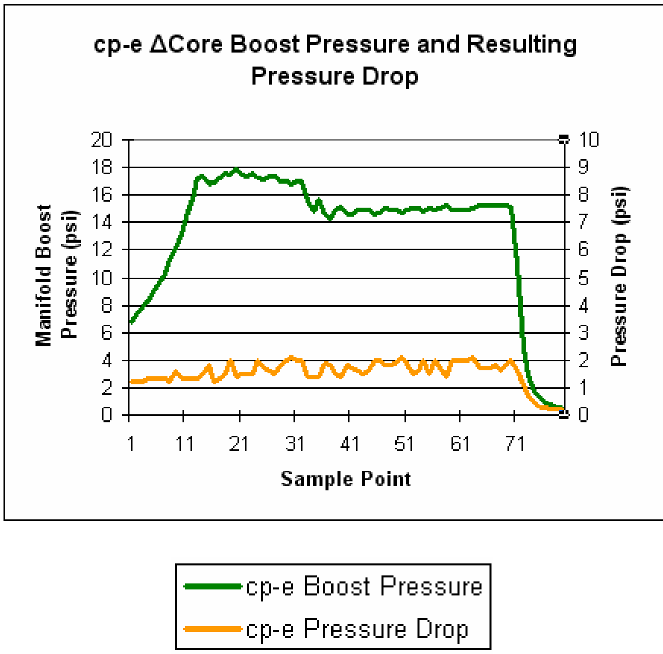
cp-e™ ΔCore™ Front Mount Intercooler

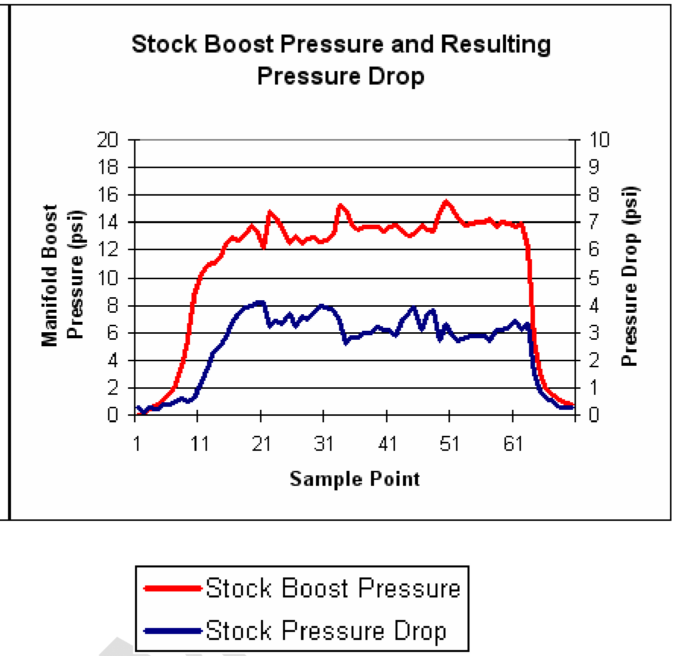
So even before you have driven anywhere, your intercooler is going to be nearly 50°F cooler just by moving it off from the top of the engine!

PRESSURE DROP:

Every intercooler will have a resulting pressure drop. In fact, if an intercooler had no pressure drop, it would not perform any cooling! That is because the heat transfer inside the intercooler takes place at the interface between the passageway walls and the air. This region is called the “boundary layer” and is also where the friction (and the pressure drop) comes from.

Part of the challenge in designing a good intercooler kit is compromising between thermal efficiency and pressure drop. Typically pressure drop and thermal efficiency are inversely related because the more pressure drop, the more the air is contacting with the intercooler, which increases heat transfer. Of course, if your pressure drop gets too large, then the turbo has to work harder then it needs to in order to maintain the desired pressure in the intake manifold, which ultimately reduces performance. So an ideal intercooler would have good thermal efficiency with a modest pressure drop. With said, let’s look at some data.





The charts above show the boost as measured in the manifold, as well as the resulting pressure drop across the intercooler. In other words, this graph is telling you how much boost the engine is seeing, and also how much pressure was lost in getting there. Although the boost pressure curves for each intercooler look slightly different the important point to consider is the maintained pressure, and the associated pressure drop. In the case of the stock intercooler, it lost nearly 4psi at some data points. That means when the engine is seeing 15psi, the turbo is actually producing closer to 19psi before the intercooler! As boost pressure increases, as it would when using a boost controller, this pressure loss will only get worse. The cp-e™ ΔCore™ FMIC on the other hand has a maximum drop of 2psi, which is much more reasonable. This lower pressure drop not only allows for shorter turbo spool times, but also puts the turbo into a healthier portion of its efficiency range, which drops outlet temperatures as well.

ENERGY BALANCE:

In the past, many of our customers voiced concerns about going to a front mount intercooler because they believed that by increasing the intake air volume there would be a corresponding increase in turbo lag (or in this case the boost threshold, or boost onset), which makes the vehicles less enjoyable to drive. The idea is that by increasing the intake tract the turbo has more volume to fill, so it'll take longer to reach a certain pressure level. Although this is absolutely true and is something any potential FMIC customer should be aware of, this actually is not an issue with cp-e™ ΔCore™ FMIC. This is partially due to the use of 2.25" hard pipes, as opposed to the much more common 2.5" pipes. As you can imagine, by using the smallest intercooler piping possible, you stand to reduce unnecessary intake air volume, which reduces turbo lag and the boost threshold.

Our reasoning for using 2.25" piping was actually very straightforward, despite the inherently chaotic nature of turbulent fluid flow. Turbulent airflow is almost impossible to model through manual calculations because of it is a truly chaotic process (i.e. totally unpredictable).

However, using some assumptions and a couple very simple calculations, we can estimate how much horsepower our selected intercooler piping can support. This calculation is based on how much friction is produced in a pipe as the air traverses through it, and is a function of the intake air velocity. As the intake air velocity increases, so does the resulting pressure drop. I will give a brief background as to what these approximations are based upon.

The first concept that must be understood is that energy is basically the ability to do work. It cannot be created or destroyed, and this concept is called, "The Conservation of Energy." This is a constant throughout the universe, and also happens to be the first law of thermodynamics. What that means is that the total energy in any system is always the same, but it gets converted into one form or another. We can also use the concept of "energy" to explain why our intercooler kit utilizes 2.25" piping.

As the air moves through the pipe, the air interfaces with the pipe walls and generates fluid friction. This friction converts kinetic energy (energy of motion) into thermal energy. So we have taken the energy of the fluid motion, and converted it into another form: Heat. We can actually quantify this frictional loss, which is also referred to as "head."

Head loss is defined as, "…the energy loss per unit mass," and can be more or less thought of as quantification of the friction generated as the fluid flows through a pipe, (Fox 336). The formula to calculate head loss is listed below:

$$h_l = f \frac{L}{D} \frac{\overline{V}^2}{2}$$

WHERE,

h_l = Head loss, (m^2/s^2)
f = Friction factor (constant value that is a function of turbulence and surface roughness, and is found using a look-up table based on experimental data), (unit less)
$\overline{V}$ = Average velocity, (m/s)
L = Pipe length, (m)
D = Pipe diameter, (m)

So using this formula, we can input information about our pipes and get some approximation as to how much energy is being lost to friction. Because the friction factor, pipe length, and pipe diameter do not change, the only variable we have to manipulate is the velocity, and we can do this through changing the pipe diameter. Obviously the smaller the pipe diameter, the faster the fluid will flow. But as pipe diameter grows, so does the time it takes to pressurize the intake. So we need to find the ideal pipe diameter to support about 450hp, as that is what our intercooler core is rated at (based on the manufacturer's 1psi pressure drop standard). However, we still do not know how much head loss is acceptable for our purposes.

So we can calculate how much friction is created in our intercooler pipes, but we still do not know how much friction is 'reasonable.' So, we look to the experts who have tested various combinations. We rely on them to collect empirical data so that they can interpret the data and create guidelines, which the product designers follow. In this case, we looked to one of the most respected names in the turbo-charging industry, Corky Bell. Bell states;

"There is probably some magic number that airflow velocity should not exceed…I suspect this number to be around Mach 0.4, or about 450 feet per second, since drag and therefore flow loss increases significantly after this. An approximate value for maximum airflow can be obtained by multiplying the desired horsepower by 1.5" (Bell 61).

SPEED3 Maximum Estimated Horsepower: **450bhp**

Estimated Airflow = 1.5*(450) = 675cfm

$$Velocity = \frac{Airflow}{Area}$$

$$= \frac{675\,\frac{ft^3}{\min}}{\pi\left(\frac{2.25}{2}\right)^2 in^2}\, x\, \frac{\frac{1}{60}\frac{\min}{\sec}}{\frac{1}{144}\frac{ft^2}{in^2}} = 407.44\,\frac{ft}{\sec}$$

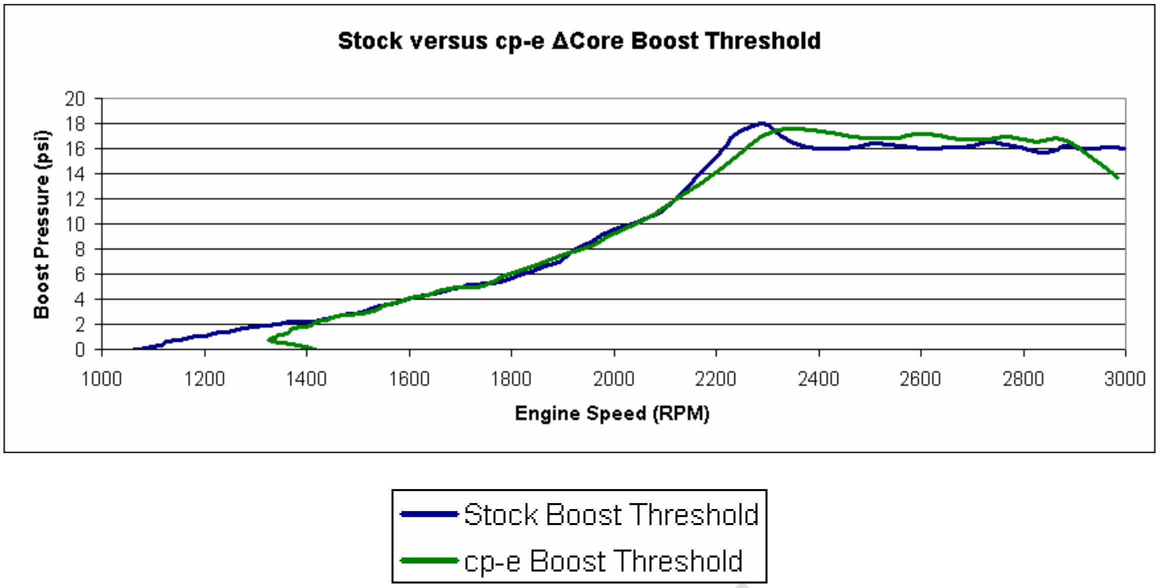
$$\text{Mach} = \frac{407.44}{1100} = 0.37$$

So, despite the modest 2.25" intercooler pipe diameter, the pipes are capable of supporting in excess of 450bhp! Of course, theory doesn't always hold true in practice, so let's see how our intercooler performs in real-world conditions.

BOOST THRESHOLD:

In this test, the vehicle was put into fourth gear at just over 1000rpm. The gas pedal was floored and the resulting boost pressure was recorded for both intercoolers. If the cp-e™ ∆Core™ FMIC added a considerable amount of volume to the intake then the resulting spool time would increase. Our hope is that utilizing modestly sized 2.25" piping, we can eliminate some lag associated with front mounted intercoolers.

As a note, we were able to record the following data using our Standback™ engine management system, which is a very sophisticated engine controller that was specifically developed for the SPEED vehicles and the CX-7. You can find more information about it **here**.



The above chart shows how boost is developed with the stock top mount intercooler and the cp-e™ ΔCore™ FMIC. Although the stock intercooler does achieve peak boost slightly before that of the cp-e™ ΔCore™ FMIC, the difference will be imperceptible to the end-user. Although it's difficult to tell from the graph, *the stock intercooler developed peak boost a mere 44rpm earlier then the cp-e™ ΔCore™*. Had we chosen to use **2.5" piping,** our spool times would have undoubtedly increased. So rest assured that the cp-e™ ΔCore™ will not create considerable turbo lag.

THE INFAMOUS DYNO CHART QUESTION:

"What about the horsepower increase," you ask? You should be highly skeptical of any intercooler manufacturer that just makes a horsepower claim as a testament to how effective their intercooler is, and here's why. There are very few dyno testing facilities that have fans that can simulate the air speeds a car might encounter on the road. In other words, using inadequate fans can greatly skew dyno results because they may only be able to simulate 20 mile-per-hour air speeds, which may favor a thin intercooler over a thick one for instance. The other reason is because you won't have any idea *why* the intercooler is making power. Is it because of a lower pressure drop? Is the thermal efficiency higher? Was the vehicle heat soaked for any of the dyno runs? Did the boost pressure, ignition timing, or air/fuel ratio change appreciably between runs? None of these questions are answered from dyno data, which is why we directly test the factors that *make* horsepower. If the thermal efficiency increases and pressure drop decreases, then you will make more power.

FINAL NOTES:

We are incredibly excited to start releasing these intercoolers because we have seen first-hand how much room for improvement there is.

<u>**STOCK TOP MOUNT INTERCOOLER**</u>	<u>**cp-e™ ΔCore™ FRONT MOUNT INTERCOOLER**</u>
Thermal Efficiency: **63%**	Thermal Efficiency: **82%**
Pressure Drop: **4psi**	Pressure Drop: **2psi**

Using our front mount intercooler, we have increased the thermal efficiency by 19%, and cut the pressure drop by half! The result is much colder intake air, and the turbo is not pumping as much waste heat into the intake charge. More than that, we have proven that our intercooler is more than adequate for the stock turbo, so those of you who want an intercooler capable of cooling a big turbo may look no further.

However, we must be very clear that other front mount intercoolers may not perform as well as ours does, so please do not take this document as a testament to *all* front mounted intercoolers' performance. We spent many months designing, testing, and tweaking our design until it was absolutely perfect. So we encourage potential front mount intercooler buyers to ask the FMIC manufacturers the tough questions. What is their intercooler kit's thermal efficiency? What methods were used to record it? What is the associated pressure drop? Do the results sound reasonable? Does the kit require any permanent modifications to the vehicle? Does it add any turbo lag? We put this document together because our intercooler kits *are* different then the competition, so please do not assume that a competitor's front mount intercooler is as good or better then ours just because it too is a front mount intercooler!

CONCLUSION:

The SPEED3 really is a special car because of how many bottlenecks exist on a stock example. It's no surprise that the best part of modifying any car is enjoying the newfound power an aftermarket part creates. So we look forward to installing well-engineered aftermarket parts onto cars like the SPEED3 because there is so much gratification when you put your foot to the floor for the first time and enjoy the added power. Purchase the cp-e™ ΔCore™ FMIC and rest assured that you are running only the finest intercooler kit available for the SPEED3. No other company delivers the quality, documentation, and customer support that cp-e™ does. If you have never done business with cp-e™ and you are still not convinced after reading this document, give us a call or stop by our shop and see what we are all about for yourself!

WORKS CITED:

Bell, Corky. Maximum Boost: Designing, Testing, and Installing Turbocharger Systems. Cambridge: Bently Publishers, 1997.

Fox, Robert et.al. Introduction to Fluid Mechanics. Danvers: John Wiley and Sons, Inc., 2004.