Intercooler flow effects from various end tank designs

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Abstract:

This paper will cover the testing of various end tank designs and how they affect flow across the internal cross section of an intercooler core. The end tanks studied are both designed to be used on a 1995-1999 Mitsubishi Eclipse GST or GSX, or 1995-1998 Eagle Talon Tsi, and the Mitsubishi Lancer Evoloution 8, for an aftermarket racing application, and to study benefits, if any, of having one end tank design over another.

Materials used are as follows:

1. Spearco 2-216 (3.5”x10.5”x28.0”) Bar and plate style air to air intercooler core
2. 1 fabricated sheet metal “typical” style end tank.
3. 1 cast, smooth volute style end tank.
4. “Squirrel cage” style furnace blower and various metal ducting
5. Davis Instruments “Turbo Meter” wind speed indicator

For experimental setup please refer to figure 1. Data from each end tank will be compared with one another, to check for differences in flow and to determine any restrictions present in the intercooler / end tank system.

Introduction:

About 4 Years ago the only thing that was available for the second generation Mitsubishi Eclipse and Eagle Talon as far as Front Mounted Intercoolers (FMIC) were the Greddy big and small kits and custom fabricated ones, which were usually composed of parts designed for other cars (universal cast end tanks), fabricated sheet metal end tanks, or kits that would require lots of hacking of sheetmetal or extra bends to get a FMIC mounted up to ones car. No installation of a performance oriented aftermarket FMIC seemed to go smoothly. More recently a plethora of FMIC kits began to hit the market. There was, however only one flaw in all of these designs: the end tanks. None of them were optimized for high, laminar, evenly distributed flow, and extremely high boost pressures. Stated best by A. Graham Bell, author of **Forced Induction Performance Tuning**, "***Perhaps the greatest potential for improvement (in intercoolers) rests in the design of the tanks on each end of the charge cooler. Here the wrong approach can muck up both airflow and cooling efficiency. Always we have to be thinking in terms of equalizing as much as possible charge flow down each tube. Keep in mind that flow losses increase dramatically in those tubes flowing more air. Also, because the volume is higher and the flow faster these tubes will draw off less heat.***"

Let us now take a short break and introduce some basic thermodynamic principles.

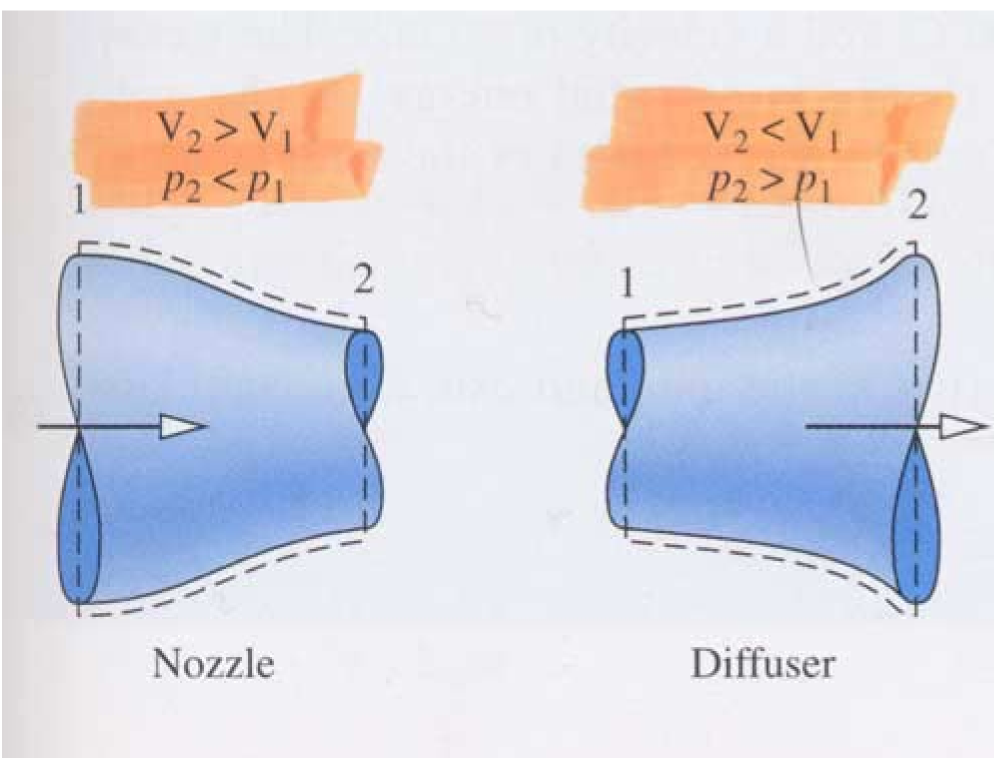


Figure 1.1

In figure 1.1 you can see that we have a nozzle and diffuser. Yes, but what are these things you may ask? A **nozzle** is a flow passage of varying cross-sectional area in which the velocity of a gas or liquid (in our case charged air) increases in the direction of flow. In a **diffuser**, the opposite occurs: the fluid decelerates in the direction of the flow. In English: these are the necessities to connect either side of your intercooler to your turbocharger and intake manifold.

Here is how these two terms apply to your turbo system: A diffuser is what is on the inlet side of the intercooler, providing a smooth transition and presenting even distribution of charged air to the intercooler. A nozzle would be on the exit side of the intercooler core where it takes the gas or fluid from a low velocity at higher pressure and increases the velocity but decreases the pressure. This is why intercoolers have pressure drops associated with them. The one in question (spearco core 2-216 was tested) has a relatively low pressure drop due to the non louvered internal fin structure, and well designed end tanks will help keep you pressure drop to a minimum as well. Taking heated compressed charge air, at high velocity and slowing it down and "spreading" out the air at point 2 (entrance to intercooler core), thus the greater pressure. This is how all intercoolers are built, a nozzle on one end and diffuser on the other. However all nozzles and diffusers are not created equal. Some people spend their entire career on nozzle and diffuser design. This is where my experiment aims to prove that all end tank designs are not created equal.

So one may ask: “What's the big deal if your nozzles and diffusers (or end tanks as us car folk like to call them) are boxy and non-optimized?” Every pipe bend or shape in a fluid system has something called a “loss coefficient” associated with it. For example, in a piping system, if you have a 90-degree bend, it has a specific loss coefficient associated with it. Again, quoting A. Graham Bell, “***To compensate for flow loss caused by bends, decrease horsepower by 5% for each 90˚ bend. Keep in mind that three 30˚ bends cause the same flow loss as a 90˚ bend.***” To make a long lesson in fluid dynamics short, this means that the fluid or gas flowing through this pipe has to expend (or more accurately, lose) a certain amount of energy to each change in direction it is undergoing. That loss is energy that your engine and turbocharger are producing that isn’t being utilized efficiently! You definitely do not want your turbocharger working harder than it needs to. Furthermore sharp bends, or complete right angle bends will have greater loss coefficients than would a smoother radius bend. Take a look at Table 1.1 for a general reference for loss coefficients.

Loss Coefficients for Pipe Components $\left(h_L = K_L \frac{V^2}{2g}\right)$ **(Data from Refs. 5, 10, 27)**

Component	K_L
a. Elbows	
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
Long radius 90°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 45°, flanged	0.2
Regular 45°, threaded	0.4
b. 180° return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
c. Tees	
Line flow, flanged	0.2
Line flow, threaded	0.9
Branch flow, flanged	1.0
Branch flow, threaded	2.0
d. Union, threaded	0.08
***e. Valves**	
Globe, fully open	10
Angle, fully open	2
Gate, fully open	0.15
Gate, $\frac{1}{4}$ closed	0.26
Gate, $\frac{1}{2}$ closed	2.1
Gate, $\frac{3}{4}$ closed	17
Swing check, forward flow	2
Swing check, backward flow	∞
Ball valve, fully open	0.05
Ball valve, $\frac{1}{3}$ closed	5.5
Ball valve, $\frac{2}{3}$ closed	210

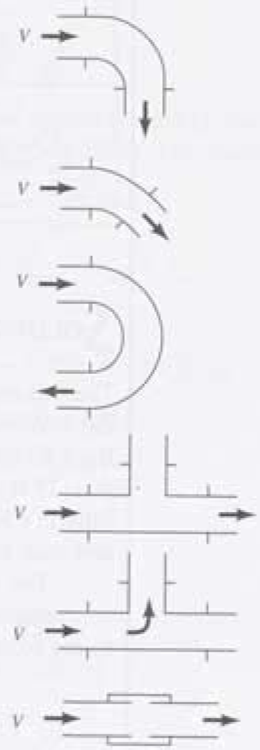


Table 1.1

Note in table 1.1a the loss coefficients of a regular 90-degree elbow vs. a long radius 90-degree elbow.

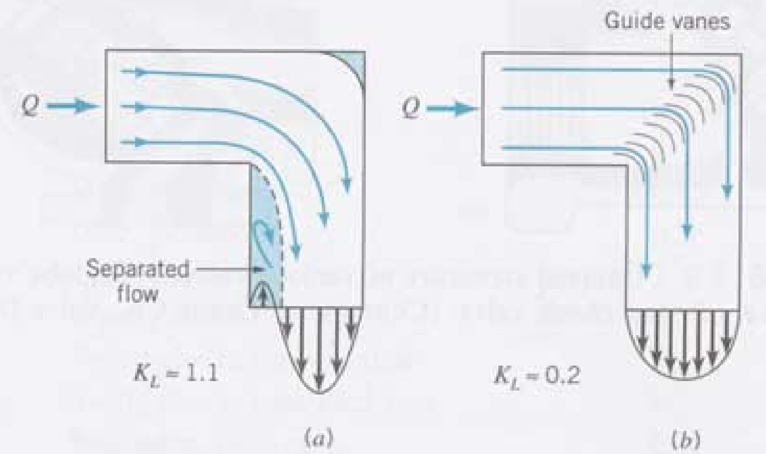


FIGURE 8.31 Character of the flow in a 90° mitered bend and the associated loss coefficient: (*a*) without guide vanes, (*b*) with guide vanes.

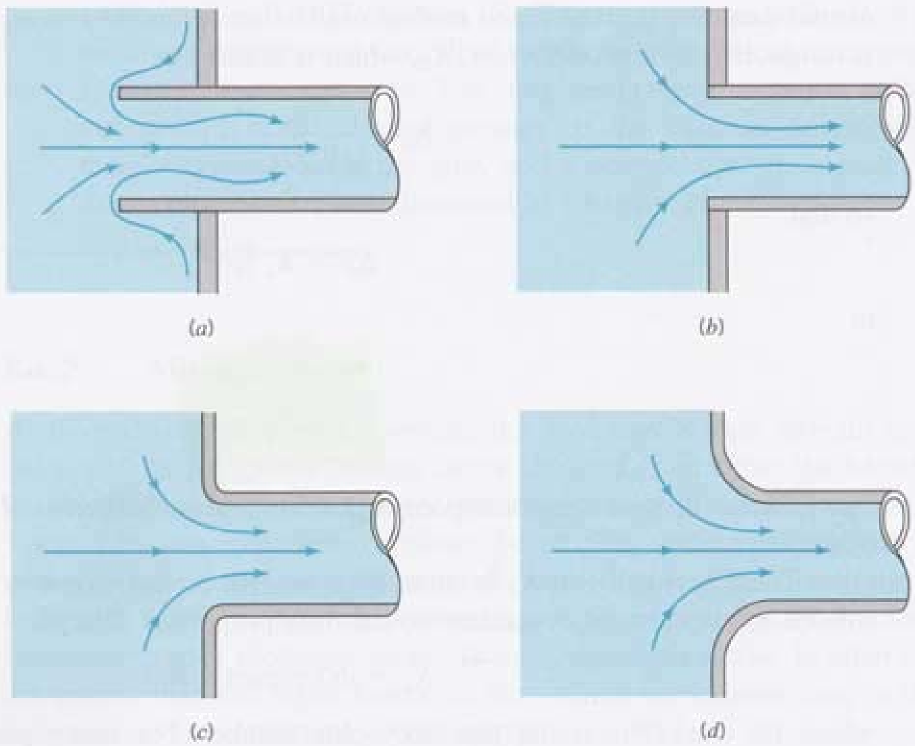
Figure 8.31

Referring to Figure 8.31 we can draw several conclusions from this. 8.31a could be thought of as a sharp right angle box, or turn. Whereas 8.31b can be thought of as a tight 90˚ mandrel bend. You can see the differences in loss coefficients, and the fact that in 8.31a separated flow starts to occur. We can draw parallels from the scenario portrayed in fig 8.31a to the end tank design in Figure 1.2 below.

a. b.

Figure 1.2

It is evident that the turbo is going to expend more energy pushing on the core or end tank walls, than it will passing through the intercooler. It is also good practice, when you are unable to optimize end tank design, to have the inlet and outlet at different levels on the intercooler, so as to evenly distribute the pressure differences. Otherwise with an inlet and outlet at the same “height” most of the flow will only utilize the rows of the intercooler directly in front of the inlet/outlet. As indicated by figure 8.31 even if the airflow were evenly distributed over the entire core you're still expending more energy.



■ FIGURE 8.22 **Entrance flow conditions and loss coefficient (Refs. 28, 29). (*a*) Reentrant, $K_L = 0.8$, (*b*) sharp-edged, $K_L = 0.5$, (*c*) slightly rounded, $K_L = 0.2$ (see Fig. 8.24), (*d*) well-rounded, $K_L = 0.04$ (see Fig. 8.24).**

Let us now relate figure 8.22b to a sheet metal end tank (shown in fig 1.2a) and figure 8.22d to the smooth volute cast end tank presented in this experiment (shown in fig 1.2b). You will notice that there is an 8% difference in the loss coefficients of 8.22b vs. 8.22d. Ok big deal. Well as a matter of fact it is a big deal. Now figure in the other end tank bringing the loss total up to 16%, and then figure in all the bends in your intercooler piping. It all adds up doesn't it? Have you taken your spare tire out to save weight yet?

Another useful figure taken from A.R.E. Cooling is shown below in table 1.2. This demonstrates airflow through different charge air tanks.

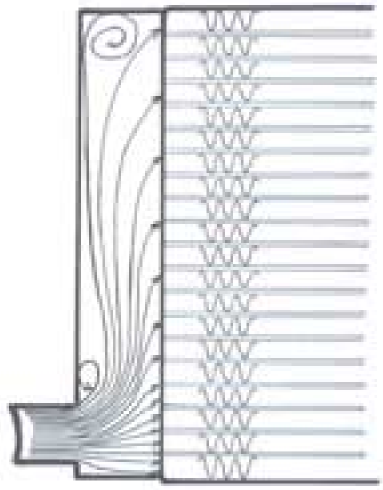
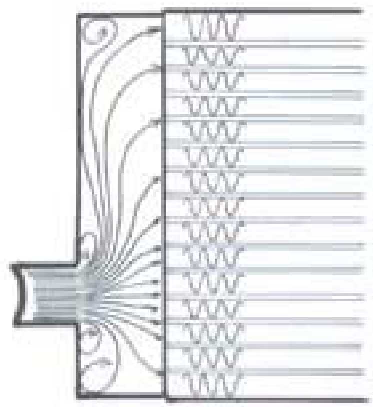
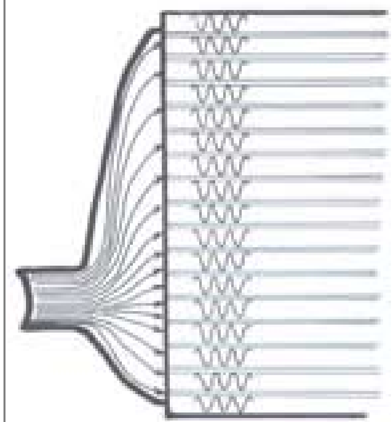
		
Most of the charge flows through the bottom 35% of core; with the top 65% causing detrimental pressure drop until high boost is reached. Worse again if other pipe is on the bottom too!!	The 2 corners cause large eddies & the square inlet corners small eddies which restrict flow & distribution across the core window. Worse if pipe is on bottom other end!!	Not perfect, but very good & very cost effective. Nowhere near as important to have diagonally opposite tanks like both designs on the left. Very small eddies & small uneven distribution across core window

Table 1.2

Results:

The testing of the intercooler flow was achieved by using a large centrifugal blower, various ducting, and a wind speed meter. Pictures of the setup and apparatus are shown below in figures 1.3, 1.4, 1.5, 1.6, 1.7, and 1.8.

Figure 1.3: Apparatus overview

Figure 1.4: Centrifugal blower and fabricated ducting

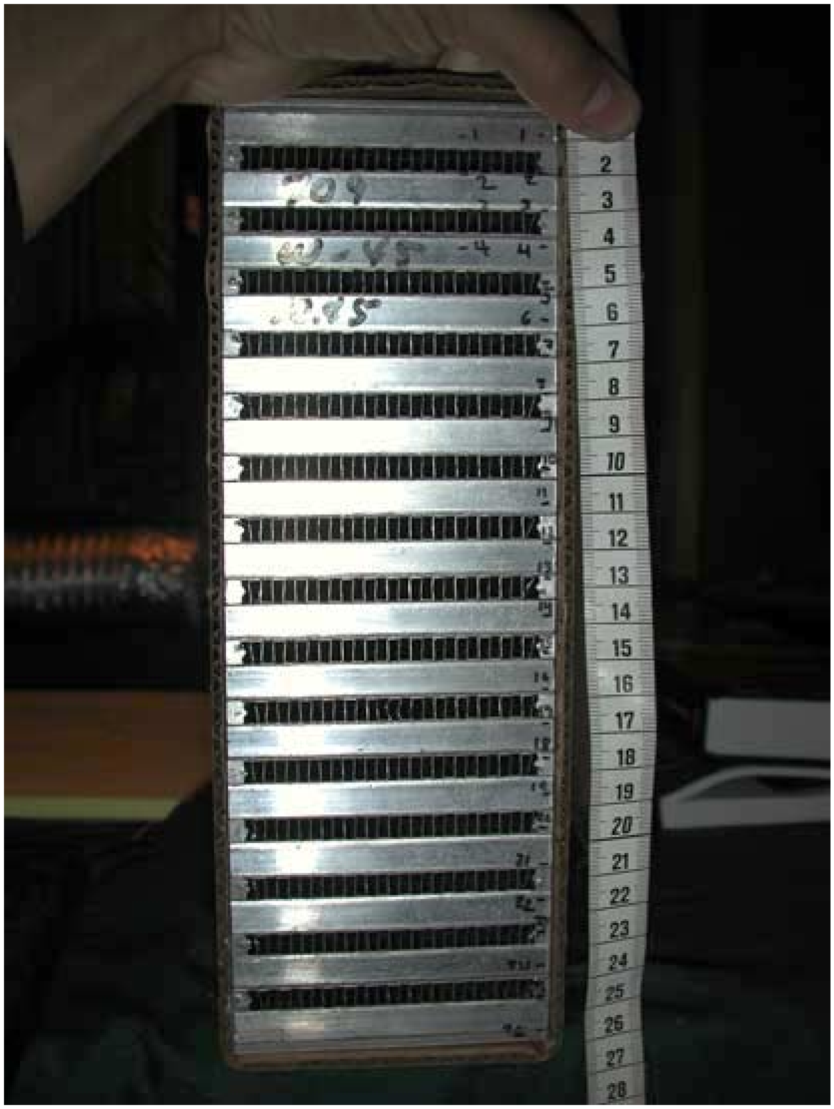


Figure 1.5: Position measurements at core end

Figure 1.6: Marks on core were aligned with center of wind speed meter. Measurements were taken in both meters per second, and miles per hour.

More often times than not, before a measurement was recorded the experimenter let the values stabilize for several minutes. Any slight disturbance in front of the core exit, would affect the values, so the experimenter had to be aware of this and careful when taking measurements.

Figure 1.7: Bottom values were recorded in one set of data (all data), and discarded in the other set of data (relevant data). These discarded values can be seen highlighted in yellow in tables 2.1 and 2.2 below.

Figure 1.8: Finally a picture of the entire setup, showing wind speed meter mounting.

Having now seen the experimental setup it should be clear that the position measurements discussed in the results below reflect position of the wind speed meter along the exit side of the intercooler core. The two end tanks used were the cast end tank shown in figure 1.2b, and the fabricated, box style end tank as shown in figure 1.2a. Furthermore it is important to note that the inlet velocity was recorded before each end tank was tested. Inlet velocity represents the total output of the blower measured at the end tank inlet. Before both trials the resultant value for inlet velocity was as follows:

Inlet velocity (mph)	Inlet velocity (m/s)
44	19.5

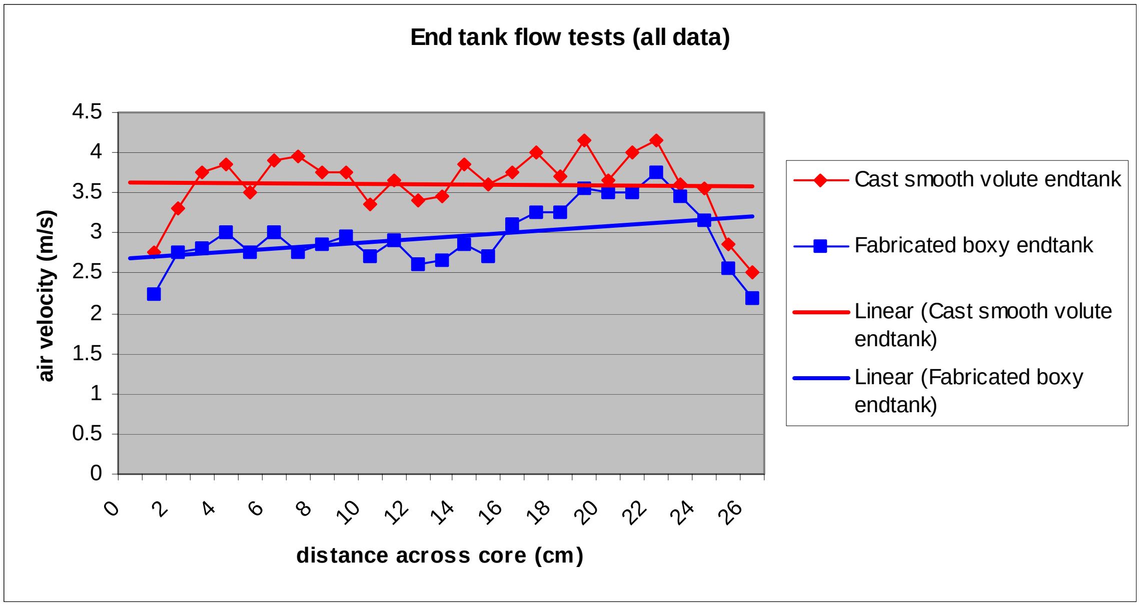
Cast smooth volute End tank			
Position (cm)	Velocity (mph)	Velocity (m/s)	Mass flow rate (kg/s)
0			0
1	6.2	2.75	0.006329182
2	7.5	3.3	0.007595019
3	8.3	3.75	0.008630703
4	8.6	3.85	0.008860855
5	7.7	3.5	0.008055323
6	8.6	3.9	0.008975931
7	8.7	3.95	0.009091008
8	8.1	3.75	0.008630703
9	8	3.75	0.008630703
10	7.3	3.35	0.007710095
11	8.05	3.65	0.008400551
12	7.45	3.4	0.007825171
13	7.65	3.45	0.007940247
14	8.6	3.85	0.008860855
15	8.15	3.6	0.008285475
16	8.35	3.75	0.008630703
17	8.65	4	0.009206084
18	8.15	3.7	0.008515627
19	9.05	4.15	0.009551312
20	7.95	3.65	0.008400551
21	8.8	4	0.009206084
22	9.2	4.15	0.009551312
23	8.05	3.6	0.008285475
24	8.05	3.55	0.008170399

25	6.15	2.85	0.006559335
26	5.55	2.5	0.005753802

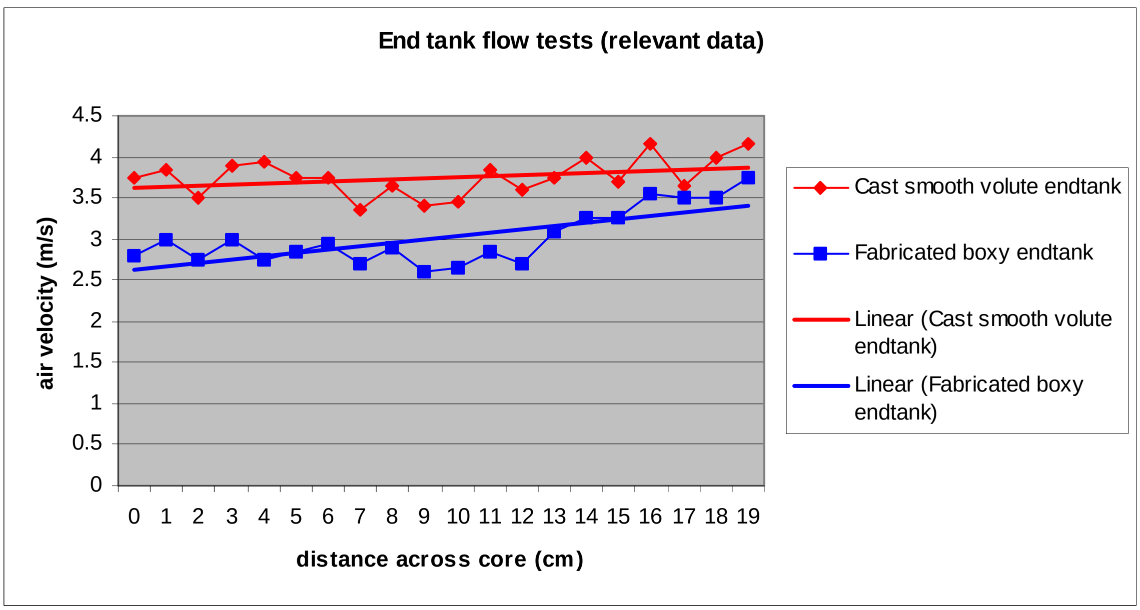
Table 2.1 – Cast end tank results

Fabricated boxy endtank		
Velocity (mph)	velocity (m/s)	mass flow rate (kg/s)
		0
5	2.25	0.005178422
6.15	2.75	0.006329182
6.2	2.8	0.006444259
6.6	3	0.006904563
6.05	2.75	0.006329182
6.6	3	0.006904563
6.15	2.75	0.006329182
6.35	2.85	0.006559335
6.5	2.95	0.006789487
5.9	2.7	0.006214106
6.4	2.9	0.006674411
5.65	2.6	0.005983954
5.9	2.65	0.00609903
6.35	2.85	0.006559335
5.8	2.7	0.006214106
6.85	3.1	0.007134715
7.15	3.25	0.007479943
7.15	3.25	0.007479943
7.95	3.55	0.008170399
7.75	3.5	0.008055323
7.75	3.5	0.008055323
8.25	3.75	0.008630703
7.55	3.45	0.007940247
7.2	3.15	0.007249791
5.65	2.55	0.005868878
4.85	2.2	0.005063346

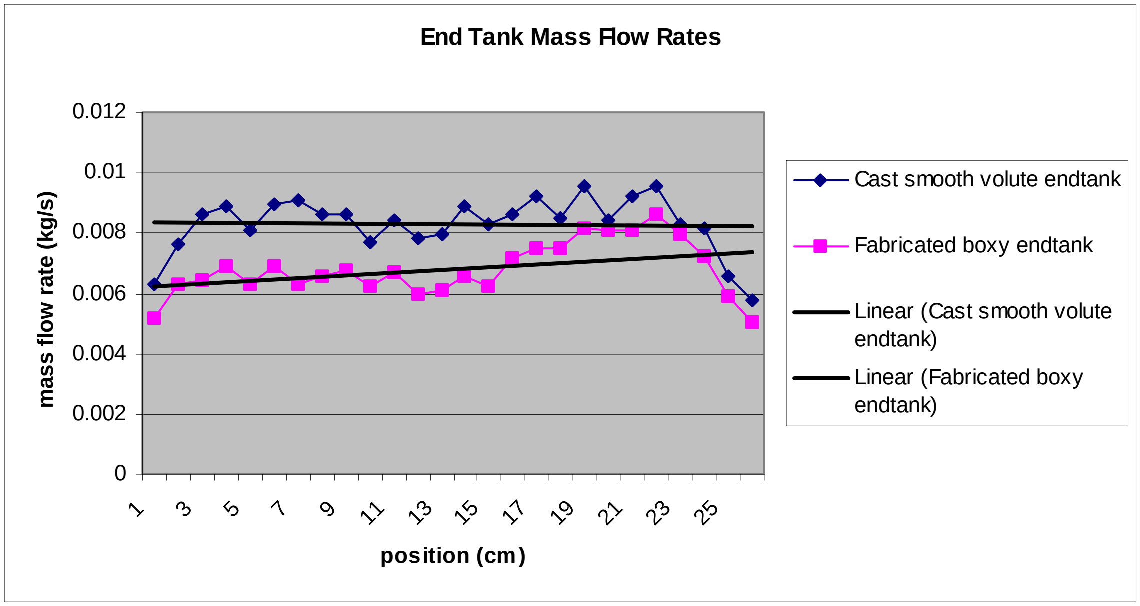
Table 2.2 – Fabricated sheet metal end tank



Graph 1.1



Graph 1.2



Graph 1.3

Graphs 1.1, 1.2, and 1.3 were all fitted with a linear best-fit line.

position (cm)	percent difference in velocity
0	#DIV/0!
1	22.22222222
2	20
3	33.92857143
4	28.33333333
5	27.27272727
6	30
7	43.63636364
8	31.57894737
9	27.11864407
10	24.07407407
11	25.86206897
12	30.76923077
13	30.18867925
14	35.0877193
15	33.33333333
16	20.96774194
17	23.07692308
18	13.84615385
19	16.90140845
20	4.285714286
21	14.28571429
22	10.66666667
23	4.347826087
24	12.6984127
25	11.76470588
26	13.63636364
avg	22.68782869

Table 2.3: Summary of percent difference in velocity, showing an average value highlighted in red.

Percent difference was calculated by taking the velocity value at a particular position for the cast end tank and dividing it by the velocity value at the same position for the fabricated end tank. The number one was subtracted from that result and then multiplied by 100 to obtain a percent difference. The resulting percent differences for each position were then averaged to obtain a result of roughly 22-23% better flow from the cast end tank. Keep in mind that this is at non-positive boost pressures, and relatively low CFM. It is the experimenters belief that at higher boost pressures, and greater CFM that greater differences in flow would be seen, and a greater percent difference in exit velocity of the cast end tank versus the typical fabricated end tank would also be seen.

Discussion:

The results include two sets of data, relevant data (graph 1.2) and all data (graph 1.1). If you look at all the data points, you will notice that at each end (position) the numbers fall off. This is because the wind speed meter was half on and half off the core at these lower points, as can be seen in Figure 1.7. So therefore in the relevant data (graph 1.2), these beginning and ending values were discarded, for both end tanks. It is also important to note why the graphs seem to be quite jagged. It is the experimenters belief that this was caused by the location of the wind speed meter, and exactly how many air flowing passages, versus end plates of the intercooler were hitting the wind speed meter, this all had to do with how the meter was positioned. That is why a line of best fit (linear) was used, this way a rough average of the jagged points could be established. To more accurately measure flow, more accurate measuring devices would need to be employed. Lastly the mass flow rates were calculated for each point using all data, and displayed in graph 1.3.

Conclusions:

That should be enough learning for today, you've already learned more about fluid dynamics than you ever thought you're brain could handle. Up until now, most sheet metal end tanks have sacrificed intercooler flow in favor of ease of fabrication, and mass production. From my testing I have found that at non-positive boost pressures (atmospheric pressure) that there is about a 23% increase in flow between a typical box fabricated end tank, and the cast ones presented herein. These findings correlate well that at higher positive boost pressures and greater cubic feet per minute of air, the intercooler will be more efficiently utilized. In a fabricated restrictive box style end tank, your turbo will expend more energy pushing on the internal walls of the end tank, instead of flowing in a laminar evenly distributed fashion through your core. Under extreme boost pressures this can also quite possibly compromise the structural integrity of the end tanks welds (possibly causing a weld joint to fail). In conclusion it is the experimenters belief that a cast smooth volute end tank is superior in performance to any fabricated end tank, for flow, fitment, and structural reasons.

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