Intake Manifold Tech: Runner Size Calculations by [MichaelDelaney]
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Intake Manifold Design for Single TB IM's with a Plenum

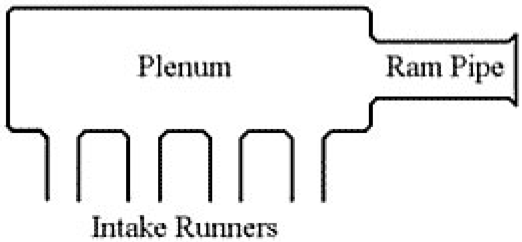
B18B IM (left and closest to you in side view pic) and ITR IM (right): Notice the ITR IM has shorter runners with larger diameters compared to the longer tunnel ram runners of the B18B.

Skunk2 IM for the GSR with it's shorter than ITR stock runners.

When race engine builders talk about fuel injected engine "parts integration", one topic of the discussion is planning out where you want your powerband to be located along the rpm range .

The induction system can be "tuned" or designed to have features which can improve the way the cylinder fills and determine where PEAK TORQUE will be located along the rpm range. This is what we call intentional "powerband location" placement.

The three features of an intake manifold with a plenum that determine peak torque location are it's:



- plenum volume

- runner length

- runner area

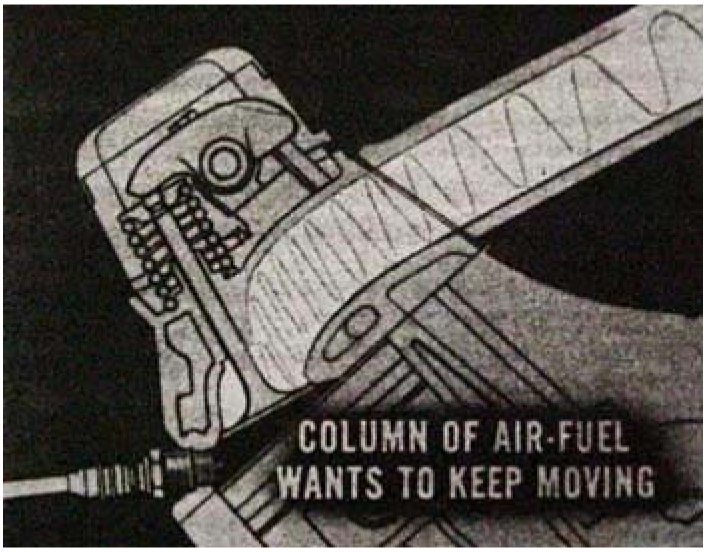
But before we proceed with how these 3 features affect cylinder filling, we should first understand how air flows in an intake manifold.

I. **RAM AIR THEORY**

Dry air is thought to behave like a compressible elastic fluid. In the "Ideas: Flow capacity, flow velocity, and flow quality" article, we discussed the differences between laminar versus turbulent fluid flow. However, instead of looking at fluid dynamics, mass air flow can also be looked at in terms of it's acoustic behaviour or behaviour as a sound wave and it's frequencies.

Sound waves travel as undulating pulsations up and down an IM runner. These pulses have a frequency or resonance and carry energy. You'll be surprised to discover that air isn't just sucked into the engine but also can be forced through the engine's intake valves even in naturally aspirated setups.

Figure 1. Air flow down an intake runner as a sound wave (acoustic resonance).

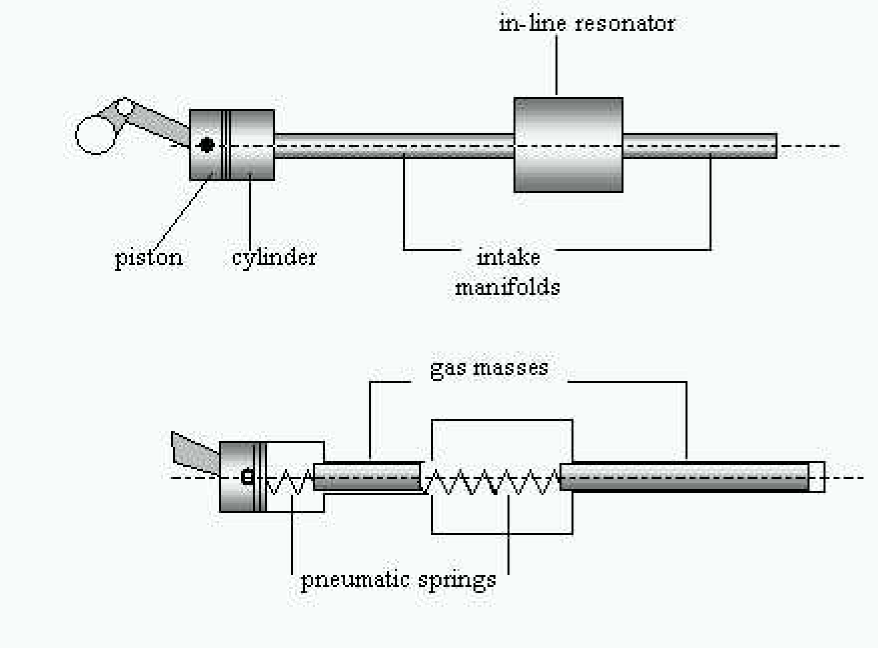


In a naturally aspirated engine, on the intake stroke, the piston drops creating an area of low pressure in the combustion chamber that is less than atmospheric pressure and as the intake valve opens, the air from the outside is set in motion down the IM runner.

Once air (as a sound wave) has been set into motion down an IM runner, **it does NOT simply stop when the intake valve is closed shut and wait for the intake valve to re-open.**

Instead, when the intake valve closes shut, this air sound wave bounces off the backface of the valve and travels at the speed of sound back up towards the IM plenum (rarefaction wave). This reflected wave has a frequency, amplitude, and negative pressure associated with it.

Once the wave reaches the plenum, the resonance wave is isolated and the plenum chamber behaves like a resonance chamber. What is a resonance chamber?



The analogy used by most mechanical engineers to explain how a resonance chamber works is that it acts like an oscillating spring (i.e. imagine the plenum acts like the spring) with a block attached on the end of the spring (imagine the air wave in the IM runner to behave like the block) . As the block compresses the spring, the spring builds or stores up energy and when the spring uncoils, the block is given a push or energy as it travels away from the spring's compressed position.

Like our block and spring, the air resonates (or compresses the spring) at a certain frequency (spring bouncing back and forth) inside the plenum and gains energy (pressure) . The air wave is then bounced back at the speed of sound down the IM runner towards the intake valve again. But this time it has been given an extra "push" from the resonance chamber. The new sound wave going to the intake valve has a positive pressure and is travelling at a higher tone or energy (higher sound frequency).

The bouncing back and forth of sound waves from the closed intake valve to the plenum and then back down again occurs over several intake valve openings continuously. Why does this happen?

These reflected resonance waves don't reach the intake valve when it re-opens and therefore continue to reflect. This continues until several reflected air sound waves (or columns) stack up (amplified) at the closed intake valve. The energy (or pressure) of these amplified (or stacked up) reflected waves build up until they reach a maximum energy (and pressure).

The trick to resonance (or sound) tuning of the IM is to have these maximally amplified waves arrive at the intake valve just as it opens . The basic mechanism of intake manifold "tuning" or design is to provide high pressure at the intake valve so that the mass flow rate into the cylinder is boosted at a given engine speed or rpm. We do this "tuning" by changing the IM runner length and diameter (area).

By building up pressure from stacked resonating (or reflected) air sound waves (or columns) and releasing this "boost" at a specific rpm, you can get higher cylinder filling [i.e. achieve a volumetric efficiency (VE) greater than the cylinder swept volume. The engine breathes at a VE > 100%] . The reflected positive pressure waves from the plenum, when it arrives at the right time, actually pushes in more air into the cylinder beyond the effects of the piston sucking in air. Not only do you control the location of where peak torque occurs by varying runner length and diameter, you get a gain in power by using the plenum's resonance effect. This is what we call " acoustic supercharging".

Since Mopar was one of the first to use ram theory in a street car, check out:

http://www.chrysler300club.com/uniq/allaboutrams/ramtheory.htm

it has a nice calculation to show how many times an air sound wave bounces back and forth before it finally reaches an intake valve that is open at your desired rpm.

Plenum volumes will vary in size depending upon the application but the general rule is that FI setups require larger plenum volumes than N/A setups. So an STR or Venom IM with a huge plenum is too big for a N/A motor. Some experts suggest that the plenum volume for a peak torque somewhere from 5000-6000 rpm should be equal to 50-60% of the "equivalent" displacement in a 4 banger. On an N/A setup the equivalent displacement = actual displacement. On FI setups, the equivalent displacement = how much volume of air is blown into the motor.

Peak volumetric efficiency occurs at peak torque. So when we "release" these built up amplified waves just at the right time into an opening intake valve, we get peak torque at that rpm.

Therefore, by designing the IM with a certain plenum volume and runner size, you can control at what rpm the engine will achieve peak torque and more importantly, you will have more power gain at that peak torque rpm from acoustic supercharging.

Here's a nice summary of resonance tuning using ram theory for an IM :

> quote:
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> ---
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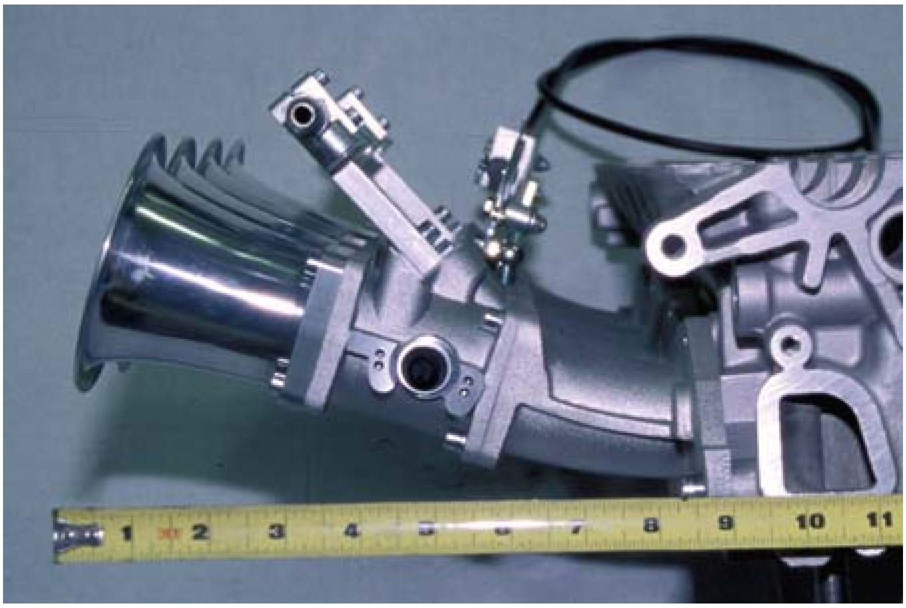
> Originally posted by Jim McFarland
>
> Every physical system has one or more "natural vibration" frequencies that are characteristic of that system .
>
> An organ pipe is a common example of how a resonant condition is displayed. Based upon the physical dimensions of an organ pipe, a flow of inlet air may produce a resonant tone or pitch.
>
> Changing the pipe's dimension, given the same amount of input air, could produce another resonant point or tone.
>
> With regard to an engine's intake {or exhaust} system, it is possible to dimension a passage to accommodate

specific cylinder displacements and engine speed so that a "resonant" condition helps produce an increase in total air flow {intake or exhaust}. In it's simplest form, this amounts to "tuning" an inlet {or exhaust} passage. Physical dimensions of the passage are constructed to provide a resonant tuning point {particularly relative to rpm and valve timing} at which a "boost" in flow is produced. This results in an increase in cylinder filling {volumetric efficiency} and potential gains in torque.



Notice that with invididual throttle bodies (ITB's) you lose this resonance effect because the reflected wave escapes out into the engine bay (or the atmosphere) and is not stored and returned by a plenum/acoustic chamber. ITB's do NOT use ram theory to get that extra kick at peak torque because they usually in race form do not have a plenum. In some street ITB's, a plenum is attached for practical reasons (sound deadening and filtering). They rely on very very large amounts of passive cylinder filling based on the piston's effects and use tuned air horn height and tapered diameter (with an S-shaped velocity stack opening) to get the N/A pressure boost effect

Jun IM Cutaway showing the velocity stack opening for the runner inside the plenum.

II. CALCULATIONS

How do we calculate and design the IM dimensions so that the stacked columns of air waves arrive at a certain rpm ?

There are 2 ways to calculate the dimensions for an IM. Using:

1. Variable length runners formulas

or

2. A Helmholtz resonator method

II A.) Variable Length Runners Formulas

From the header tech article you have learned that longer tubes create peak torque at an earlier rpm. This is true whether you are looking at air flow in terms of a fluid or in terms of a sound wave.

> quote:
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> from http://info.connect.com.au/staff.connect.com.au/lheather/318ti/1998-10/msg00764.html
>
> By choosing the length and diameter of the runners, an intake manifold can be "tuned" for optimum performance at a certain RPM range.
>
> Longer, narrower runners favor lower RPM's because they have a lower resonant frequency, and the smaller diameter helps increase the air velocity.
>
> Shorter, wider runners favor higher RPM's because they have a higher resonant frequency, and the larger diameter is less restrictive to air flow.
>
> ...Choosing the right length and diameter of the intake runners is a trade off between high and low RPM performance.

[Moderator's Note: we can use 2 sets of runners with different lengths in one IM in order to have 2 different peak torques and overcome this tradeoff. However, the penalty for using 2 sets of runners is an increase in surface area which diminishes flow quality at higher rpm and therefore limit upper rpm power (eg. Integra GSR's 2 stage IM with dual variable length runners). The problem of added area is neatly solved in the new 4th generation Integra RSX Type S 2 stage IM by using a roller valve.]

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1. / One Formula: David Vizard's Rule for IM Runner Length

The general rule is that you should begin with a runner length of 17.8 cm for a 10,000 rpm peak torque location, from the intake opening to the plenum chamber. You add 4.3 cm to the runner length for every 1000 rpm that you want the peak torque to occur before the 10,000 rpm.

So, for instance, if peak torque should occur at 4,000 rpm the total runner length should be 17.8 cm + (6 x 4.3 cm) = 43.6 cm.

Vizard also suggests that you can calculate the ideal runner diameter by the equation :

SQRT [(target rpm for peak torque x Displacement x VE)/ 3330]

SQRT = square root

VE = Volumetric Efficiency in %

Displacement in Liters

eg.

So if we want peak torque at 5800 rpm at 95% VE in a teg, VE = 0.95

SQRT [(5800x 1.8 L x 0.95)/3330]

= 1.73 in. or 43.8 mm (1,73 x 25.4 mm/in.) is the ideal runner diameter.

2./ Another Formula to Calculate Runner Length for a Specific Peak Torque RPM: from Steve Magnante at Hot Rod magazine

N x L = 84,000

where N represents the desired engine rpm for peak torque and L is the length in inches from the opening of the runner tube to the valve head.

3./ Website Calculator

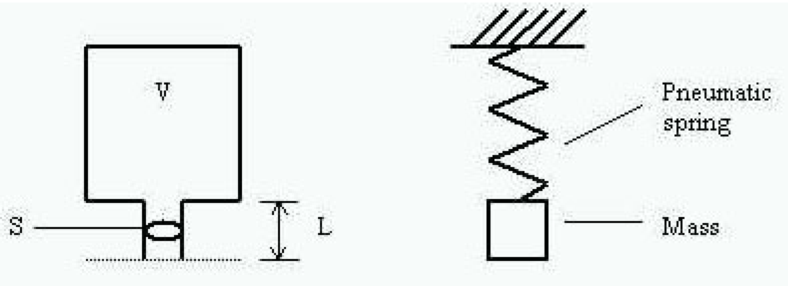
Or you can forget the formulas and just plug in the numbers and this calculator will crunch out the numbers for you:

http://www.rbracing-rsr.com/runnertorquecalc.html

II B.) Helmholtz Resonator Calculations

Remember at the start of the article I mentioned that the dimensions of 3 parts of an IM can affect where peak torque can occur? Well here is another way we can calculate estimates for our IM dimensions for the peak torque location we want.

A Helmholtz resonator is an acoustic resonance chamber (as described by our plenum above) that modifies the acoustic frequency of a sound wave like a spring oscillating with a mass attached on the end.



$$f_H = \frac{c}{2\pi}\sqrt{\frac{S}{LV}}$$

where f = the rpm at which you get peak torque (the natural frequency of pressure oscillations in the acoustic chamber) , c = the speed of sound (= 340 m/sec.) , S = runner area, L = runner length, V = displacement per cylinder

A simplified version of this is using the Englemann formula for the above which also takes into account static CR of the engine:

RPM for peak torque =

642 x c x [SQRT (S/[L x V])] x [SQRT { (CR-1)/ (CR+1) }]

= 218,280 x [SQRT (S/[L x V])] x [SQRT { (CR-1)/ (CR+1) }]

For a more detailed explanation on the application of Hermann Ludwig Ferdinand von Helmholtz's acoustic resonator theory applied to intake systems, please check out:

http://enaf1.tripod.com/teche.html#helm

http://www.mecc.unipd.it/~cos/DINAMOTO/risuonatore/risuonatore.html

A Helmholtz resonator is used not only in an automotive induction sytem but also in the designing of exhausts to suppress sound and many other non-automotive designing that involves amplifying sound like in the music industry.

III. RAM INTAKE TUBE DIMENSIONS

What are the best intake tube dimensions for the IM that we have just designed for a particular peak torque rpm?

III a./ INSIDE DIAMETER (D) of a RAM INTAKE TUBE

First Method:

D in inches = SQRT [(Displacement x VE x Redline) / (V x 18.5)]

Displacement = Total Displacement in Liters, VE = Volumetric Efficiency in %, V is the velocity of the air flow in the IM plenum for resonance (usually estimated at 180 ft/sec max.)

eg. SQRT [(1.8 x 85 x 8500) / (180 x 18.5)]

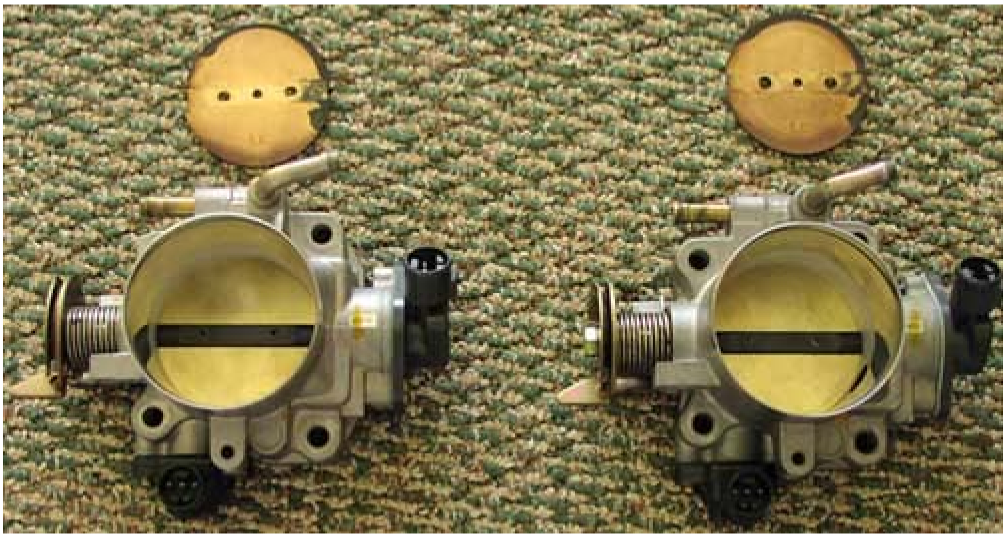
= SQRT [(1,300,500)/ (3330)]

= SQRT (391)

= 1.98 in.

Second Method:

Throttle Body Size is Determined by IM Plenum Size.



quote:

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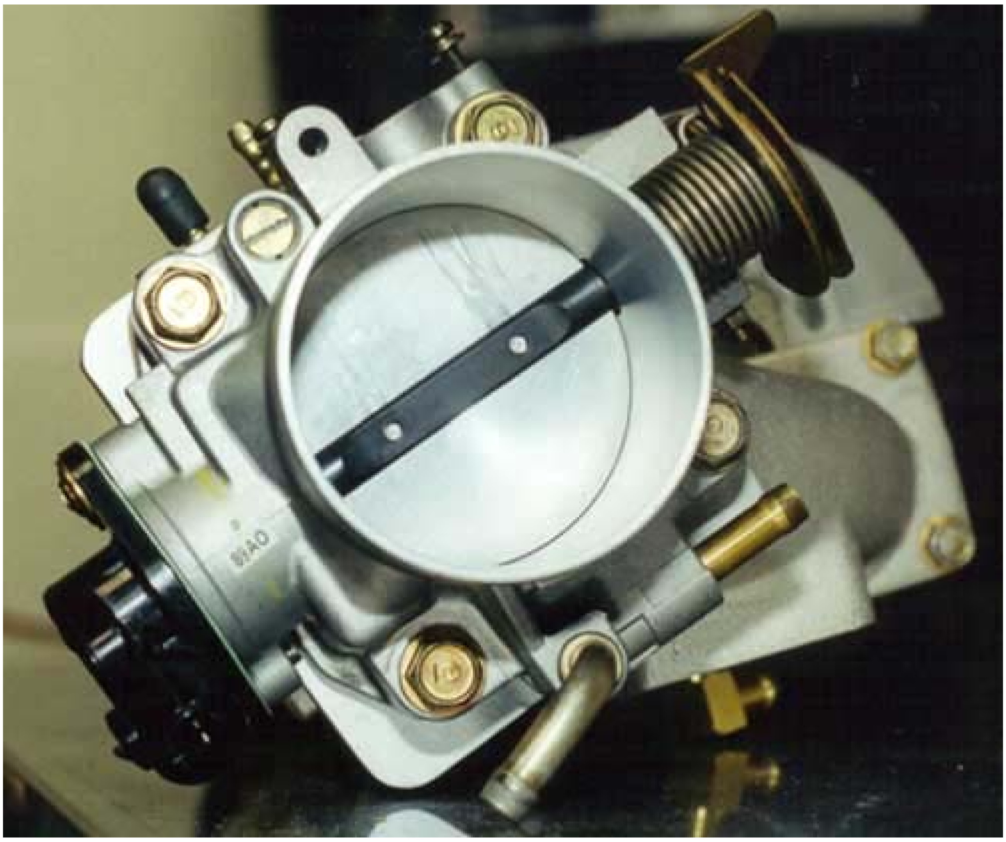
from the Dave Thompson of Thompson Engineering and Endyn: http://www.theoldone.com/archive/intake-manifold-design.htm

The plenum volume is critical on N/A engines, and a basic rule of thumb is: The smaller the plenum, the lower the rpm range, and bigger means higher rpm. The throttle body size and flow rate also affect the plenum size: Bigger TB, smaller plenum, small TB, larger plenum.

The best way to find out if your TB is too small for your IM plenum is to determine what the intake manifold absolute pressure (MAP) sensor is reading (in the plenum) when you are at full throttle (or wide open throttle (WOT)) while the car is accelerating using a datalogger. The MAP should be equal to, or close to, atmospheric pressure. If it isn't or there is a MAP drop at WOT, then your TB is still too small.

A 70mm (at the intake side or TB opening) to 65mm bore (at the plate side) ITR taper bore

TB: More than enough for most big N/A Teg engines.



Once we have determined the optimal TB size for our IM, we can then determine the best intake inner diameter.

The ideal diameter for an intake is when the intake has **25% more cross-sectional area than the TB's bore cross-sectional area** . Your TB diameter (overbored or not) dictates your intake diameter.

Remember that the area of a circle (your TB bore) is pi x radius squared and the diameter = 2 x radius. If you calculate your TB's area and then multiply it by 1.33, you will determine the intake's area. Then, use the area of the circle equation to determine the intake's radius.

Therefore, for example, with a 64mm (plate side bore) TB, the calculated "best" intake diameter is 2.8 in. ID.

III. b/ LENGTH OF RAM INTAKE TUBE

A suggested starting point for the length of a tube with peak torque at 6000 rpm is 13 in.

You add 1.7 in. for every 1000 rpm that you want to move the peak torque below 6000.

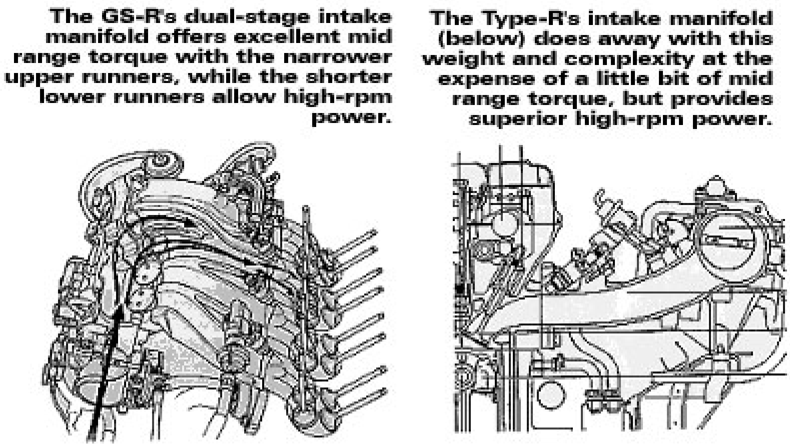
Or subtract 1.7 in. for every 1000 rpm you want to move the peak torque above 6000.

For more info on specific intakes (short rams versus CAI's etc.) please refer to my intake tech article over at hondavision.com :

http://www.automotivetech.org/forum/showthread.php?s=&threadid=3956&perpage=15&pagenumber=1

Please remember that formulas only serve as starting points. To get the actual best IM runner dimensions and intake dimensions for your particular engine package takes a cut and try approach to zero in on the best dimensions for you.

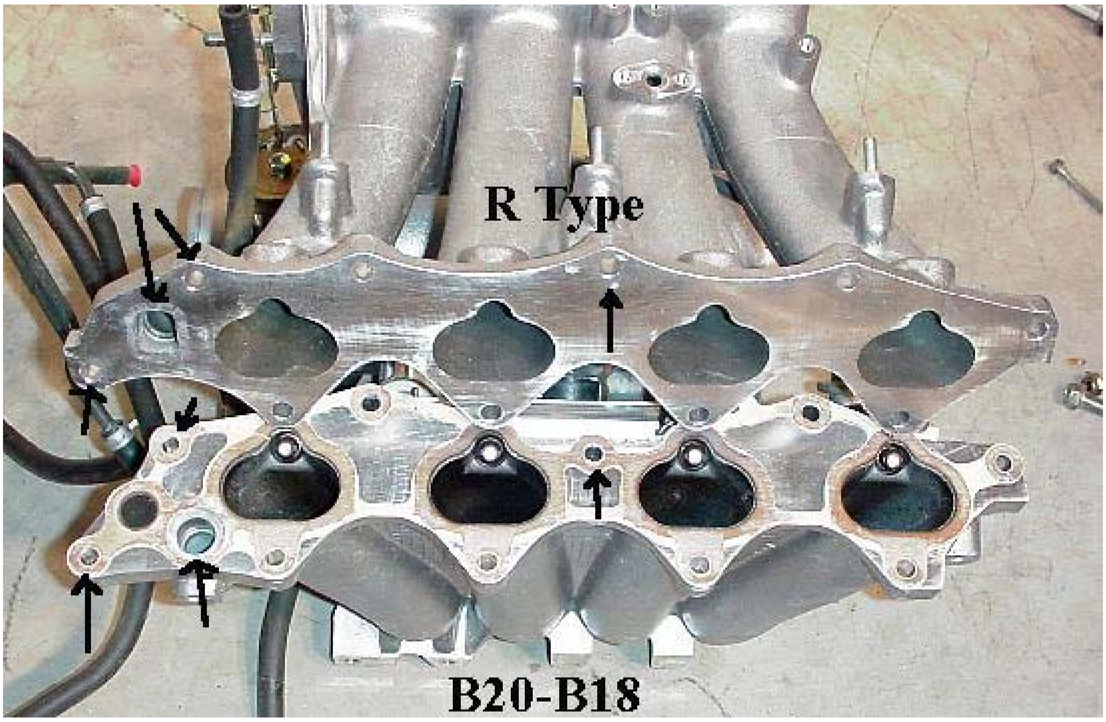
For more info on Integra Specific IM designs (Single Stage versus Dual Stage) please check out my IM Tech Article over at hondavision.com :



http://www.automotivetech.org/forum/showthread.php?s=&threadid=4673

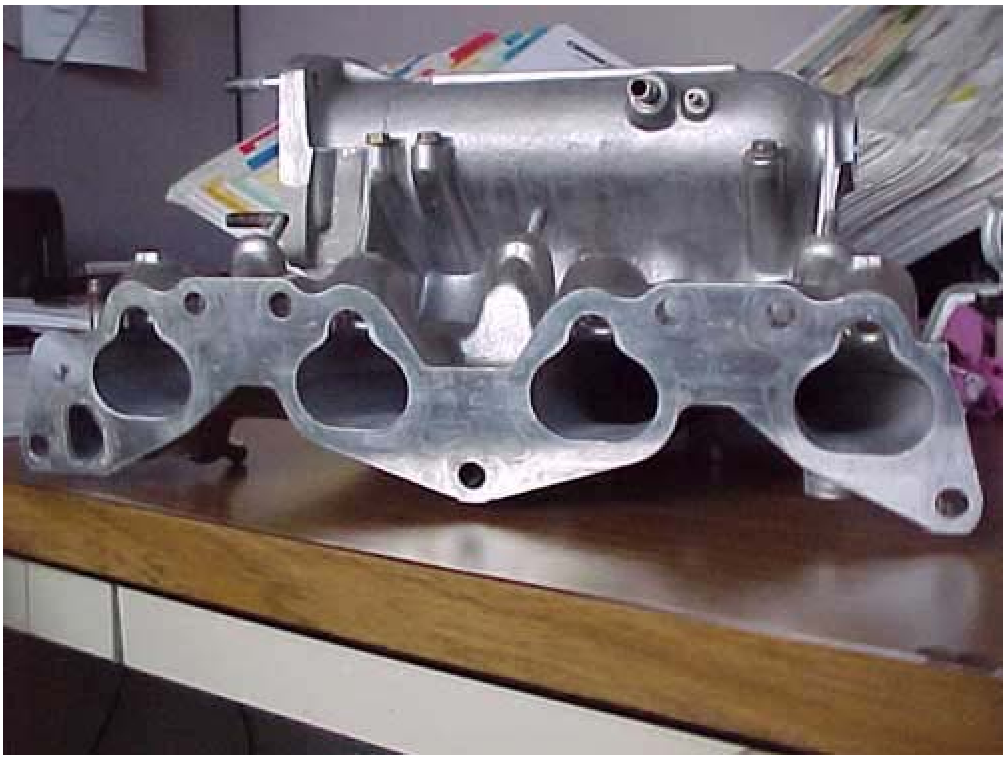
for those B18A/B and B18C1 owners looking for more top end and want to retro-fit an ITR IM onto their head, remember that the coolant & oil passages and flange bolt holes don't align and you will need machine shop work to make them fit without coolant and vacuum leaks.

Notice the flange holes and coolant passages (arrows) don't line up when you compare an ITR IM to a B18B IM:



There's a nice article on retro-fitting an ITR IM onto a B18B here:

B18B IM (affectionately known as "the Giraffe" for it's long narrow tunnel ram runners: no wonder the B18B powerband is midrange oriented.)



http://www.overboost.com/story.asp?id=85

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