# CHAPTER NINE

# COOLING AND INTERNAL AERODYNAMICS

## COOLING AND INTERNAL AERODYNAMICS

The very first priority in the design of any racing car should be the provision of adequate engine cooling. If the car won't cool it cannot be driven long enough to find out if it is capable of doing anything else. Further, the entire budget will soon be consumed in the rebuilding of cooked engines. We run into two problems here—one having to do with human nature and the other with geography and the seasons. The first is that cooling provisions, for reasons which escape me, tend to be both afterthoughts and underestimates. The second is that most of our racing cars are designed to be run in England which is a relatively cool Island and are tested in the early spring when it is just downright cold. This last bit is also true of U.S. made racers. The car whose oil and water temperatures stabilize at 85° C. at Snetterton in March is very likely to be pronounced satisfactory and released for production. Doubtless this is due to the euphoria which often clouds early testing—on both sides of the Atlantic. Since engine temperatures enjoy virtually a one-for-one relationship with the ambient temperature, this optimism is going to be of very little comfort to the customer on a nice hot day at Riverside. Touring and GT car cooling packages are usually designed around far less horsepower than the race car puts out.

The internal combustion engine is thermally inefficient. Woefully so. Depending on engine design, between 15% and 30% of the total heat of combustion must be dissipated to the airstream via the oil and the water (or air). This is one hell of a lot of heat. By the way, don't assume that the engines are 70-85% thermally efficient—most of the rest of the heat goes out the exhaust or is radiated. Getting rid of it involves the use of heavy, bulky and expensive heat exchanges and plumbing lines. The heat exchangers are very liable to be vulnerable, and they are going to cost us a significant amount of aerodynamic drag. Both the weight and the drag penalties can be minimized by efficient design.

## HEAT EXCHANGER CHARACTERISTICS

Every transfer of heat between two fluids—and what we are trying to do is to transfer a percentage of the heat of combustion from the two cooling fluids to the airstream—is directly proportional to the mean temperature difference between the two fluids, to the area of interface between the two fluids and to the volume of the cooling fluid flow. In other words, in order to increase cooling we must increase the surface area of one or both sides of the heat exchanger or we must increase the volume of the airflow per unit time through the core. Maximum area of the cooling interface is a question of heat exchanger design, and we'll briefly look at that aspect first.

Obviously what we want here is the maximum cooling area within the minimum physical dimensions. By concentrating liquid tubes and air fins we can achieve a surface area of well over 100 times the frontal area of the heat exchanger and still maintain efficient air flow. It's not quite that simple (it never is). Efficient design means narrow air fin passages and lots of them plus excellent thermal transfer between the liquid tubes and the air fins. The designer must have a pretty good idea of the viscosities of the two fluids involved and their flow rates, as well as the expected temperature differential between the fluids and the amount

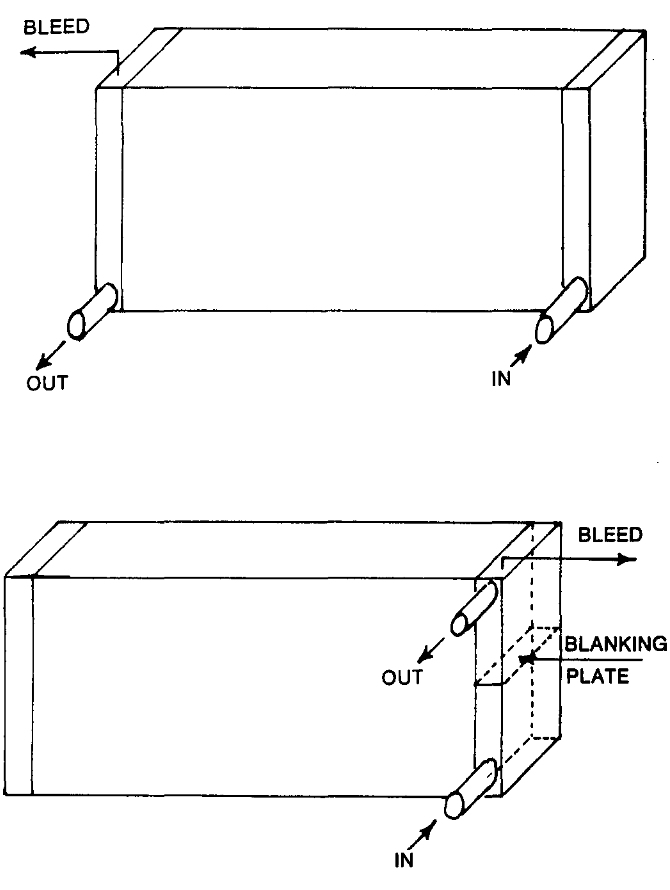


*Figure (59): Conversion of single pass water radiator to double pass.*

of temperature drop that the heat exchanger must achieve. This means that the design of heat exchangers is a job for specialists. It also means that efficient heat exchangers are designed for specific applications—or at least specific types of applications. This is the reason, for example, why large automatic transmission coolers, no matter how cheap they may be, do a poor job of cooling engine oil in a race car. As a matter of fact, they also do a poor job of cooling automatic transmission fluid.

We don't need to know how to design heat exchangers. We do need to know which of the available ones are suitable for our purposes—and why.

We are concerned with two separate types of liquid to air heat exchangers—water and oil—let's right now stop using the term, "radiator." Radiators used to be used to heat houses. Heat exchangers are used to cool race cars. Efficient water units will feature flat water tubes, usually about 3/32" high by 3/8" wide, they will not be in line with each other and the unit will feature a vast number of air fins. It will not be painted—although, if it is aluminum, it should be anodized or have a very thin coat of baked-on trick heat exchanger paint.

English cars come through with either Serck Speed or Marston water coolers. They are both excellent units—although they tend to be a bit thin in the core thickness department for our conditions. Replacement cost is ferocious. The USAC racers virtually all use G & O cores which are outstanding. Your best bet when you need a radiator is to find a good local shop that stocks G & O cores and have them make your radiator. It costs very little more to go up in core thickness and the extra cooling capacity will be more than worth the additional weight and drag—the only "Kit Cars" that I know of which had adequate cooling for U.S. racing were the '76 and '77 Marches. Minimum efficient core thickness is two inches with four inches being an absolute maximum.

There are conflicting opinions as to the desirability of aluminum water coolers. My own opinion is that they are just very nearly as thermally efficient as the more popular copper and brass units and a damn sight lighter. I run them when I can. They are also more expensive, more difficult to modify and to repair. The very best aluminum units are made by Standard Thompson, and no one can afford them. The Harrison parts which are made in a variety of thicknesses and sizes for Corvettes are excellent. Modine also makes some. All of these units can be sectioned across the tanks on a band saw to change their heights—of course you then get to weld on new tank plates, but you will have to weld in your own inlet and outlet tubes anyway. Unfortunately, there is nothing you can do to change the width of any of the proprietary coolers. The VW Rabbit comes with a very efficient and very light aluminum unit. If the dimensions are suitable for your installation, it could be ideal. Due to the elastomoric join between the tubes and the tank it cannot be modified and its pressure capacity is limited. Use the stock VW pressure caps.

If you are having a minor water temperature problem, converting your heat exchanger from the normal single pass configuration to double pass is usually worth about 5° C. Figure (59) shows the layout and it is not necessary to achieve a perfect seal between the blanking plate and the inside of the tank. You will have to re-route one water line or the other. Given a choice, come in at the bottom and out at the top. All that happens here is that each individual drop of water is forced to pass through twice the tube length of a normal single pass radiator.

## OIL COOLERS

The best oil coolers that I have found are the English Serck Speed units distributed in this country by Earl's Supply. They are relatively inexpensive, come in one width, one core thickness and several heights. They are also available with male AN ports which makes plumbing more pleasant and neater. They offer better heat rejection per unit weight and volume, less oil pressure drop and less aerodynamic cooler drag per unit of heat rejection than any other cooler which I have had tested. Southwind Division of the Bendix Corporation, Air Research, and Harrison make very good coolers for aircraft. They are very expensive and were designed for higher airstream velocities than we reach, which makes them a bit less efficient than the Serck Speed units for race car use. Modine makes a very good range of automotive oil coolers but they are expensive, bulky and hard to find. Mesa makes a cooler which, at first glance, looks similar to the Serck Speed. It is not similar and it is not efficient. The aftermarket auto transmission coolers—all of them—are useless for our purposes. As a matter of fact, you will greatly increase the reliability of your tow vehicle, camper or whatever if you throw away the transmission cooler that is on it and install the appropriate Serck. Sometimes you can get lucky and find good oil coolers in the surplus houses—but you have to be careful. Many of the surplus units were designed for stationary applications and don't work efficiently at our airspeeds.

Before we get away from the heat exchanger side, here are a few tips:

(1) Do not paint your heat exchangers. Black radiator paint, beloved of all radiator shops, instead of promoting heat transfer, actually acts as a thermal barrier and reduces efficiency.

(2) Keep the air fins straight so as not to block the flow through the core. A plywood or aluminum cover, taped in place while the radiator is out of the car, saves a lot of tedious fin straightening.

(3) When using multiple heat exchangers remember that the greater the difference in temperature between the liquid to be cooled and the air that is doing the cooling, the greater will be the temperature drop across the cooler. This has two ramifications of interest to us. First, plumb multiple coolers in parallel rather than in series. Second, do not mount your oil coolers directly ahead of or behind your water radiator. The air coming out of the water matrix is just about at water temperature and won't do much of a job of cooling the oil and vice-versa. I am perfectly aware that many good race cars have been getting away with one or the other (or both) of these sins since time immemorial—but that doesn't make it right—or efficient.

(4) A heat exchanger doesn't work very well if the liquid side is full of air. This means that oil coolers should never be mounted with both inlet and outlet ports on the bottom, that every effort should be made to de-aerate the

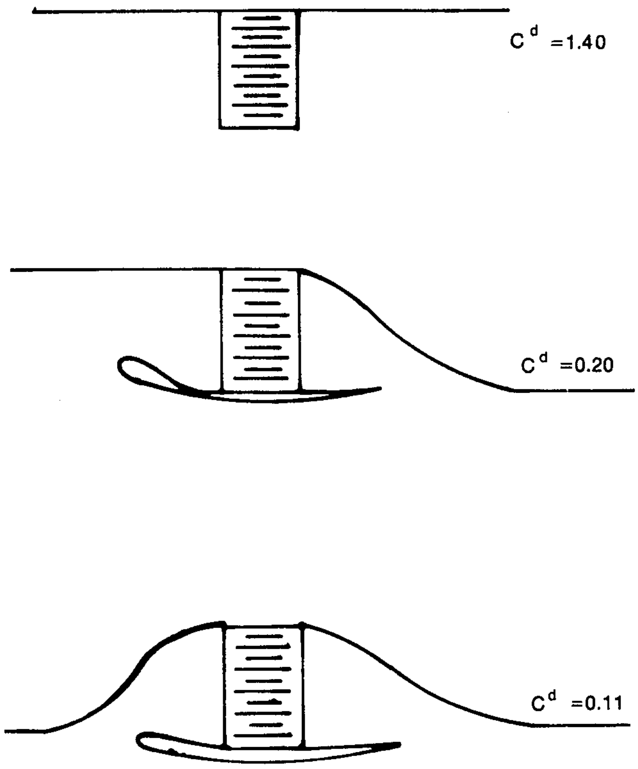


*Figure (60): Drag coefficients for various cooler installations.*

oil before it gets to the cooler and that all water coolers must have a small diameter bleed from the top (outlet side) back to the header tank.

Inadequate engine cooling can be caused by bad heat exchanger design, inadequate heat exchanger size or by insufficient cooling air flow with the latter being more common. On the water side, we can also get into trouble by pumping the water through the cooler too fast—but that is almost always due to running a stock water pump too fast and is, at any rate, beyond the scope of this book.

## AIR FLOW AND DUCTS

If we want a flow of air to cool something, we have three choices: We can ignore the problem and hope that it will either take care of itself or go away. We can hang the item to be cooled out in the open airstream. Or we can build a duct for it. In the case of liquid to air heat exchangers, we normally have some choice in both dimensions and design of the cooler. In the case of ducts we have virtually unlimited choice—which can be confusing. If you want maximum cooling for minimum size, weight and drag you are going to have to build a duct. Hanging the thing out in the open is hopelessly inefficient. Figure (60) which shows the result of some pre World War II experiments with the drag of ducted and unducted heat exchangers should make a believer out of almost anyone.

Fortunately for the racer the aircraft industry did a lot of subsonic ducting research in the 1920 s and 30 s. Unfortunately, a lot of this information is not directly transferable to race cars because the birdmen were concerned with relatively narrow speed ranges. They were not at all concerned with what might happen when the aircraft assumed a yaw angle relative to the airstream. Neither are a lot of race car designers. They should be.

Very little of current aircraft expertise is valid for our purposes. The aircraft are too fast—they are into compressible flow which changes the whole picture. As with wings, what works for them will not work for us.

For a given heat exchanger, the rate of heat dissipation varies directly with the mean temperature difference between the cooling surface and the air stream, approximately the .6 power of airstream velocity and the .8 power of air volume through the core. Both thermal efficiency and internal drag are reduced by slowing down the air velocity in the core. This means that we need high energy (i.e., laminar and high velocity) air coming into the duct and that we want to slow the air down before it gets to the core. In order to provide an extractor effect and to ensure that the exiting air is travelling at or near free stream velocity when it rejoins the freestream, we also want to accelerate the air after it has passed through the cooler and before it rejoins the freestream. To achieve all of this, we need a duct.

A properly designed duct is made up of five parts as shown in Figure (61). First we have an *inlet* which allows the entrance of the right amount of air. The inlet is followed by an expanding section called the *diffuser* in which the incom-

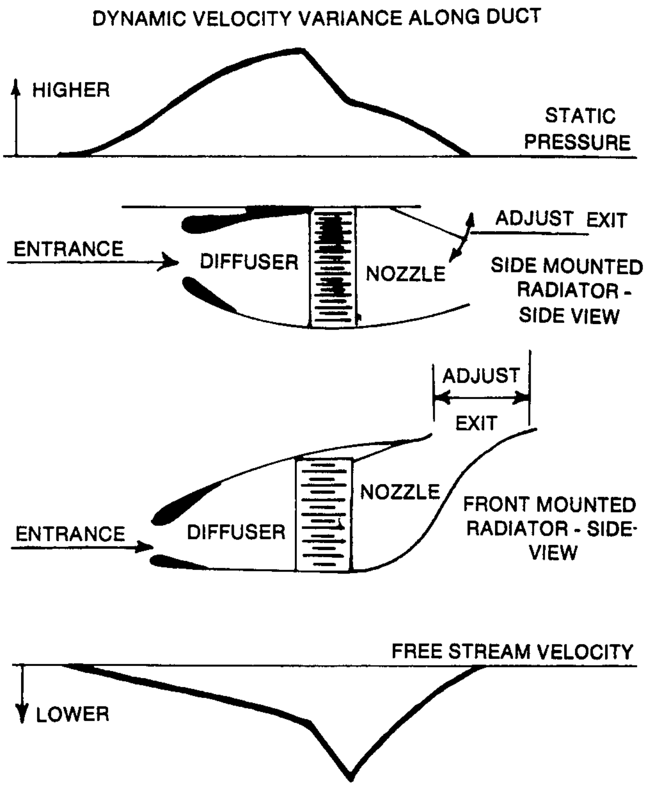


*Figure (61): Typical ram type heat exchanger ducts.*

ing air follows Mr. Bernoulli's theorem and trades some of its velocity for pressure. The diffuser will also direct the incoming air through whatever (hopefully minimal) directional changes are necessary before it reaches the *obstruction* (heat exchanger in this case) in which it is heated (and therefore expanded). Leaving the obstruction the air flows through a contracting chamber termed the *nozzle* which is very often mistakenly left off of race cars. The purpose of the nozzle is simply to reaccelerate the air up to free stream velocity so that when it rejoins the freestream at the duct *exit* it will do so in the most orderly fashion possible. Velocity differences and/or direction changes at the exit point invariably lead to drag producing turbulence, which we don't need. As a point of interest, during World War II clever people on all sides of the conflict were able to use the combination of the adiabatic heating and expansion of the air in the core plus near optimum nozzle and exit design to produce a net thrust at cruising speed instead of a drag. To achieve this they always used a variable area exit and sometimes a variable area entrance, because the areas which were most efficient at cruising speed were inadequate at take off and landing speeds. We cannot achieve this laudable aim for that very reason. We are not allowed to create moveable aerodynamic surfaces and even if we were, the small gain in total drag would not be worth the trouble. In fact, all of our ducts will end up being slightly inefficient at top speed—otherwise the entrance would be too small to provide cooling at the medium speeds where we spend most of our track time.

Let's attack the duct section by section. The critical factors for the inlet are location, area and edge radius. The inlet must be located in a region of high pressure and laminar air flow. If your chosen area is not such, then you will have to make it such or your duct will not work. It also helps a lot to get the inlet up off the track surface in order to pick up cool air. There can easily be a 20° F. difference between the air temperature at the surface of the track and ten inches above the track surface. This is one of the reasons why the attempts to pick up cooling air under the nose have always been unsuccessful. If the inlet is in the nose of the car, or raised artificially into the airstream, then we don't have to worry, being in a high pressure region of laminar flow unless it is behind a downforce ledge. Virtually anywhere else on the car, we do. Remember that the boundary layer exists everywhere and it gets thicker as we move toward the rear. By definition the boundary layer has very little energy. We must keep it out of our ducts or our air flow volume is going to be much lower than we think it is—or than it could be. The solution as shown by Figure (62) is simple enough. Either move the duct inlet far enough away from the body surface so that the boundary layer can't get in or install a splitter in the duct to direct the boundary layer around the end of the heat exchanger. This last method requires a gap between the heat exchanger and the bodywork. To find out how thick the layer is you can either use yarn tufts on a safety wire matrix or a simple water manometer—or you can guess.

If there is a way to calculate the optimum inlet area for a given race car duct I don't know about it and I wish that I did. Our road speed variance gets to all of the formulas. In the aircraft industry accepted practice ranges from 1/8 to 1/4 of the heat exchanger cross-sectional area. For us 1/4 is

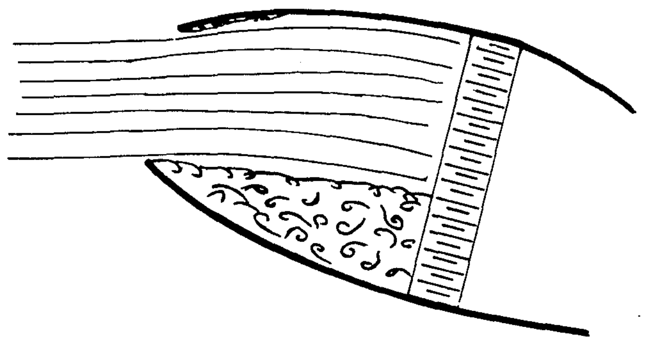

*Figure (62a): Flow in duct with "knife edged" entrance at 15° yaw angle.*

about minimum and we may have to use 60% for a poorly located duct—as in side mounted radiators. It is not an exact business and I highly recommend testing with rough ducts which allow both entrance and exit areas to be varied with aluminum and tape.

Many race cars are equipped with duct edges that approach knife edges. These work on hypersonic aircraft and they are easy to make. They do not work on race cars—particularly when the race car is sideways—even at relatively moderate yaw angles. If we are sideways to the road we are also sideways to the airstream. If we are sideways to the airstream a knife edge is going to develop a turbulent wake—quite a wide one. If this turbulence enters a duct, the duct, by definition, becomes inefficient for so long as the car is in a yaw state. Figure (62) illustrates. We deliberately spend a lot of our track time in yaw attitudes so we must radius the edges of all duct intakes—generously. A radius of 1/4" is the minimum—1/2" is a lot better.

The diffusor is not very critical. About all we have to do is blend smoothly from the area of the inlet to the area of the heat exchanger, keeping the wall angles in the eight to fifteen degree area—the smaller the angle the better. If we must exceed this angle because sufficient duct length is not available, then we may have to use internal vanes or splitters to direct the air and keep from effectively blanking part of the core due to detached flow on the duct walls.

At the heat exchanger face all we have to worry about is getting as good a seal as we can without being ridiculous. Given any kind of a chance, air will follow the path of least resistance and gaps between the duct walls and the heat exchanger are definitely the path of least resistance. Since we do not want the skin of the duct to rub on the heat exchanger, weatherstrip is the answer.

As with the diffuser, the internal design of the nozzle is very much a case of close enough is good enough. The one thing that must be avoided, however, is the all too common practice of asking the air to exhaust against a surface virtually normal to its direction of flow. This is often done in the case of front mounted heat exchangers and plays hell with the air flow.

The exit must be in a region of lower pressure than the inlet. It will only flow downhill. If a natural low pressure region is not available, or needs help, a small kicker plate just upstream of the exit will produce one. For development testing, the exit area should be made adjustable to allow playing until you get it right.

## BREAKING THE DUCT RULES

Changing the direction of airflow as it passes through a heat exchanger core is rightfully considered an unnatural act. So are a lot of other things. Quite often mounting the core at an angle to the natural airstream is a very convenient way to increase the cooling area—as in Lola T 332's and many varieties of USAC and Formula One Cars. We get away with this, at some cost in drag, by breaking the rules of ducting. In this case a converging or decreasing area duct will work better than expanding diffuser. What happens here, as illustrated by Figure (63b) is that the pressure across the face of the core is kept pretty constant by allowing the air velocity to remain constant in the duct. In this way we get more or less equal air flow through all areas of the core. What is lost in efficiency is gained back in heat exchanger volume. In this case three inches is probably the maximum core thickness before drag gets out of hand.

The once common practice of hanging the oil coolers out in the open at the rear of the gearbox is indefensible on several grounds. It is aesthetically objectionable, renders the coolers vulnerable to minor crash damage (for which reason the FIA has outlawed the custom, and other sanctioning bodies should follow suit), makes long oil lines necessary and creates a lot of unneeded work when gear ratio change time comes along. The coolers are also very liable to mess up the flow on the underside of the wing.

For a while we saw a trend toward mounting the water coolers vertically alongside the engine and parallel to the longitudinal axis of the car. Mr. Postlewaithe originated the idea on the Hesketh ne Williams and, at the time of writing, the Williams still features this configuration. The idea here is to suck the air through the core from the relatively high pressure area outside to the relatively low pressure area inside. Some cleverness is necessary to make sure that the low pressure is of sufficient magnitude to ensure an air flow. Even if it is, the cooler size has to be very large indeed—although the core thickness is necessarily small. The advantage lies in reduced cooler drag. The disadvantages include increased weight and rearward placement of that weight (the extreme rearward static weight distribution of a few years ago turned out to be a not so good idea from the low speed understeer point of view).

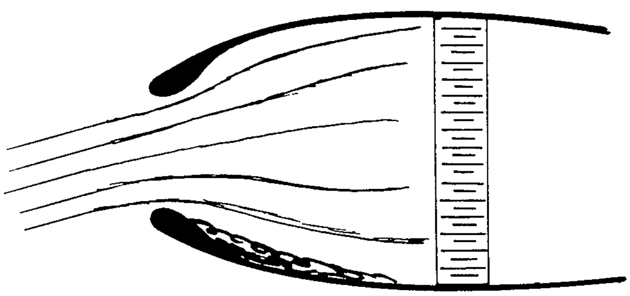

*Figure (62b): Flow in radiused entrance duct at 15° yaw angle.*

A half way measure that enjoyed a great vogue for a time was the less than clever practice of hanging the water coolers just outboard of the rear suspension radius rods, also without a duct.

At the moment, most of the Formula One Brigade mount their coolers amidships. There is no general agreement on the type of ducts, but I think that the Lotus is the most clever of all—in addition to optimum placement from the weight distribution point of view, they have very efficient looking ducts which probably generate a measurable amount of downforce.

We have been talking about ram ducts. There is another type, more subtle, more difficult to make work and considerably more efficient. These are variously called flush ducts, submerged ducts and NACA (National Advisory Council for Aeronautics) ducts and, at one time and another, have been extensively used on racing cars. Figure (64) shows a typical installation. The principal advantage here is that since they do not involve a hole in the nose or an addition to frontal area they do not measurably add to profile or parasitic drag except for the drag of the cooler itself. There is also liable to be less downstream disturbance of the air flow.

The disadvantages are that, in order to work they must be constructed very closely to the design laid out in Figure (65); they must be located in a region of laminar flow with a shallow boundary layer; they must be aligned parallel to the *local* air flow and they tend to take up a lot of room. If the designer deviates very much from any of the above, then the

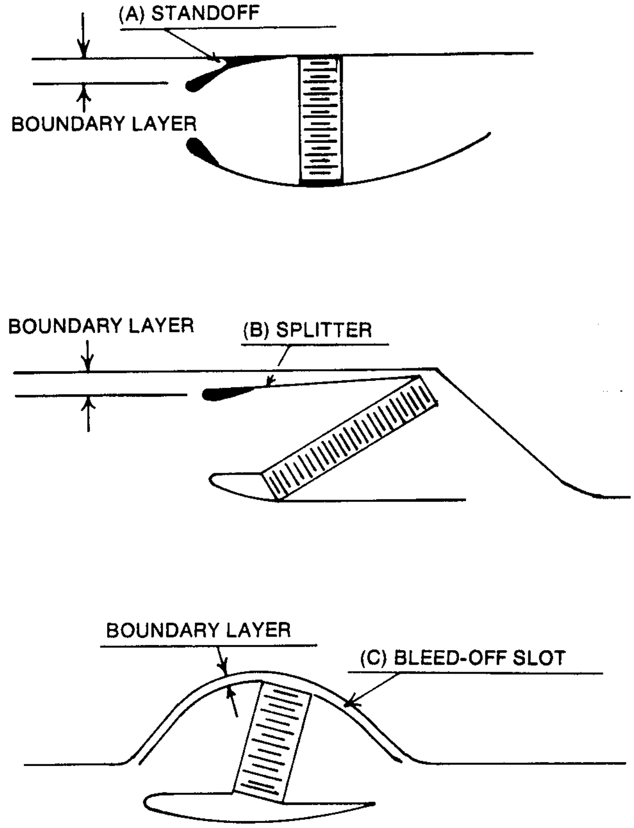


*Figure (63): Alternate of preventing entrance of boundary layer into duct.*

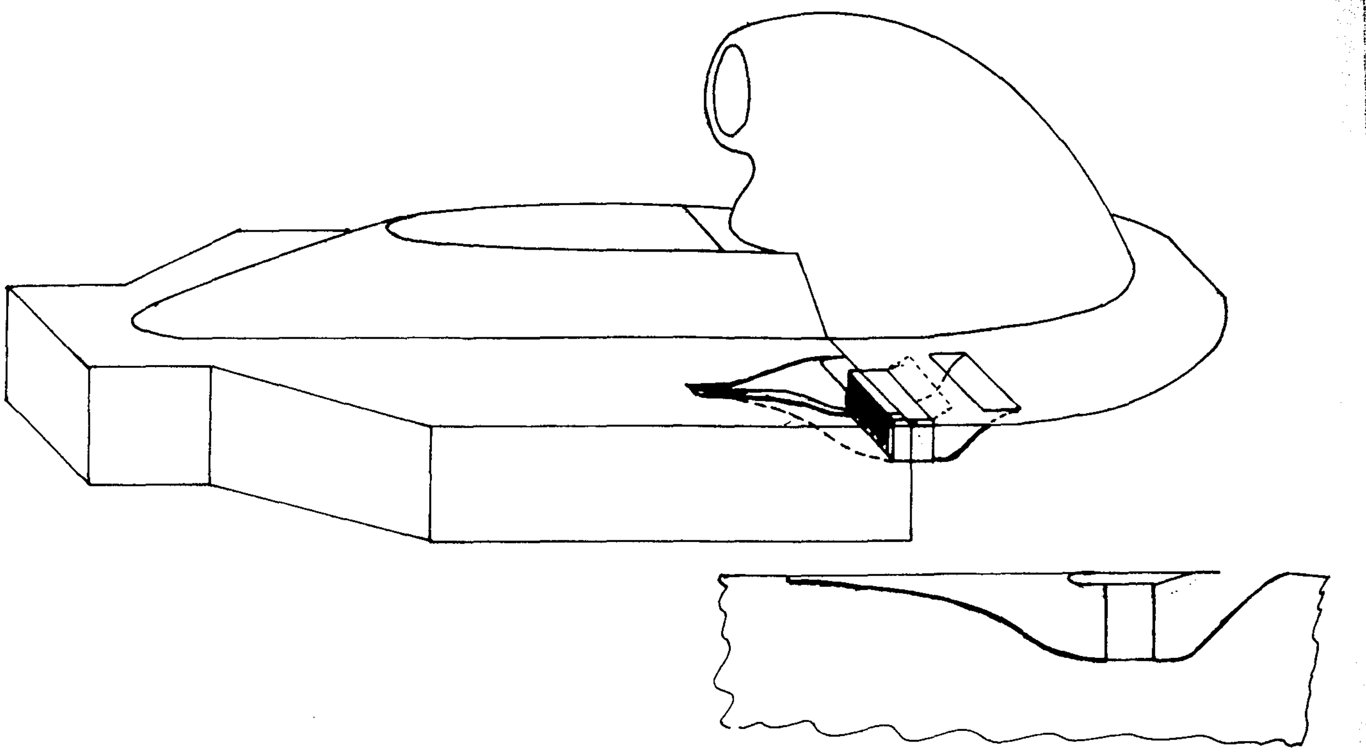

*Figure (64): Installation of oil cooler in NACA duct.*

flow into the duct is dramatically reduced, the hoped for cooling doesn't happen and NACA ducts are one more time pronounced unsuitable for racing cars. There are obvious areas where NACA ducts will work very well. Properly aligned to the airstream, they will work on any forward facing part of the bodywork with a positive pressure gradient—i.e.—an upslope or a region of increasing cross-sectional area. Since the thickness of the boundary layer generally increases as we move aft from the nose of the vehicle, the further forward the duct is located, the more efficient it will be. They make excellent front brake and shock cooling ducts. They make lousy rear brake ducts because the flow is almost always at least partially separated by the time you get that far back (although they work well on the vertical surface of well designed Formula Car engine covers/air boxes. They also work quite well on the horizontal surfaces of the bodywork outboard of the cockpit on both Formula and Sports Racing cars and less well of the vertical sides of the body in the same area (much more turbulence and a thicker boundary layer). I don't favor their use for water radiators because it is not possible to arrange the duct dimensions required. I do favor their use for the much smaller oil coolers, brake ducts cockpit cooling, etc.—particularly on Sports racing cars with their acres of bodywork.

The important aspects of the design of the NACA duct itself (as opposed to its location) are that the angle of the ramp floor should be kept at a maximum of ten degrees; the ratio of duct depth to duct width should be as high as practical (deep ducts); there must be a radiused lip at the rear of the skin opening and the duct corners must be kept square. With NACA ducts as with any others, the exit region is at least as important as the entrance—the air must have somewhere to go and just hoping that it will happen isn't good enough. The duct must also be sealed and smooth. Very often we have to make wide and shallow ducts which will also be much shorter than optimum design. We can get away with all of this so long as the duct is properly located and we pay sufficient attention to the other parameters. It is also possible to get depth by the sides of the duct above the surface of the bodywork but this tends to be expensive and probably isn't worth doing.

## ENGINE AIR BOXES

Current practice in Formula One and Formula Two should convince us that engine ram air boxes must contribute significantly to overall vehicle performance. I am an air box addict and have been for a long time. A properly designed air box can do several things:

Increase engine power by increasing the flow of air through the engine and by providing the coolest available air to the engine.

Even out the distribution of air to the intake stacks.

Smooth out the flow of air to the rear wing, thus reducing the amount of drag induced for a given downforce.

However, it isn't easy to arrange all of these admirable features—or even part of them. The development period was both long and confusing. For several seasons we saw most of the Formula One Teams trying the air box of the week—and often throwing them away in practice and running the race with naked intakes. Finally, as so often happens, everyone figured out the way to do it and we had a couple of seasons with every team running virtually identical air boxes. These all had very large intakes, complete with generous radii. The intakes invariably lived well up in the breeze—just behind and over the driver's head. The inlets fed large diffusors which also served as plenums, and the bases of the diffusors were sealed to the intake stacks. The outside shape was carefully sculpted both to reduce drag and to provide a smooth flow of air to the rear wing. Not only did they work, they looked good and they moved the aerodynamic center of pressure aft for increased aerodynamic yaw stability.

For 1976 the C.S.I. decreed high air boxes illegal and development started all over again. The air box of the week returned and was frequently discarded. This time, however, previous experience had convinced all the Teams of the advantages of a working air box and they are starting to look alike much sooner than before. The exceptions are Ferrari and Brabham/Alpha whose flat twelve engines with low intake stacks allow the use of a really elegant system—they take the air in through two large NACA ducts located on either side of the vertical cockpit surround and feed it into a low plenum neat!

The V-8 brigade has pretty much settled on a pair of inlet horns extending into the airstream on either side of the driver's head and feeding a central plenum. The shape of the intake has not yet been standardized.

So what is actually required to make an air box work—and why do so many of them not work?

| $X/X_{max}$ | $Y/Y_{max}$ |
|---|---|
| ° 0 | 0.042 |
| 0.1 | 0.070 |
| 0.2 | 0.102 |
| 0.3 | 0.138 |
| 0.4 | 0.178 |
| 0.5 | 0.227 |
| 0.6 | 0.295 |
| 0.7 | 0.377 |
| 0.8 | 0.460 |
| 0.9 | 0.496 |
| 1.0 | 0.500 |

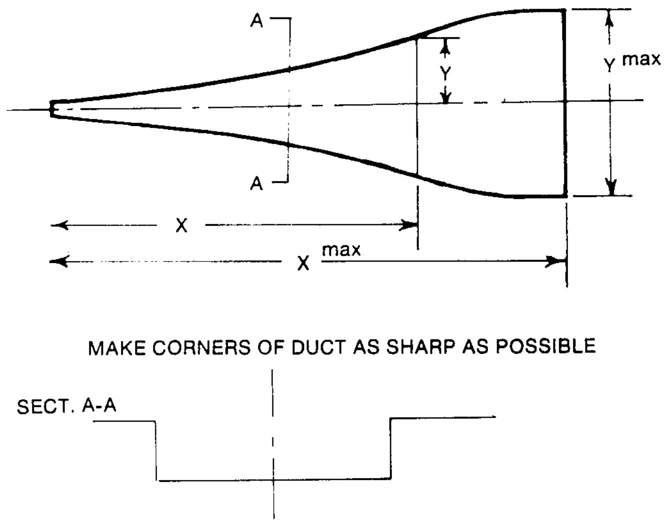


*Figure (65a): NACA duct co-ordinates—plan view.*

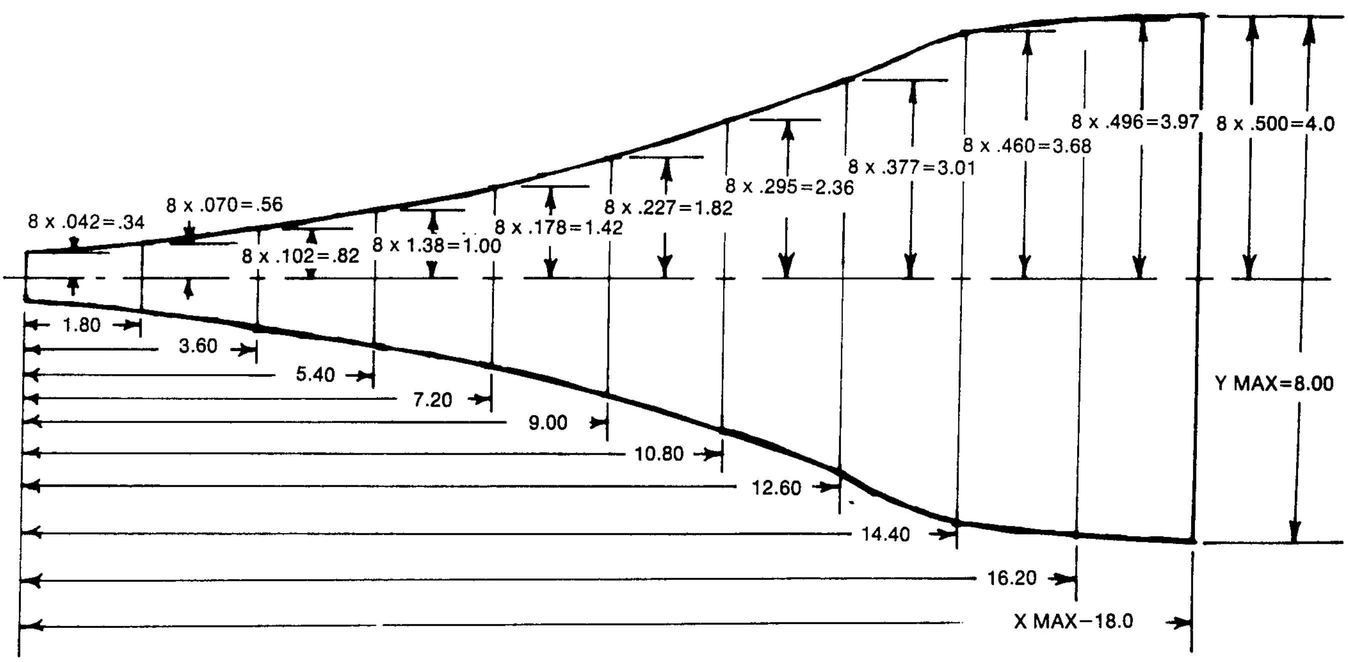


*Figure (65b): Layout of NACA duct—plan view.*

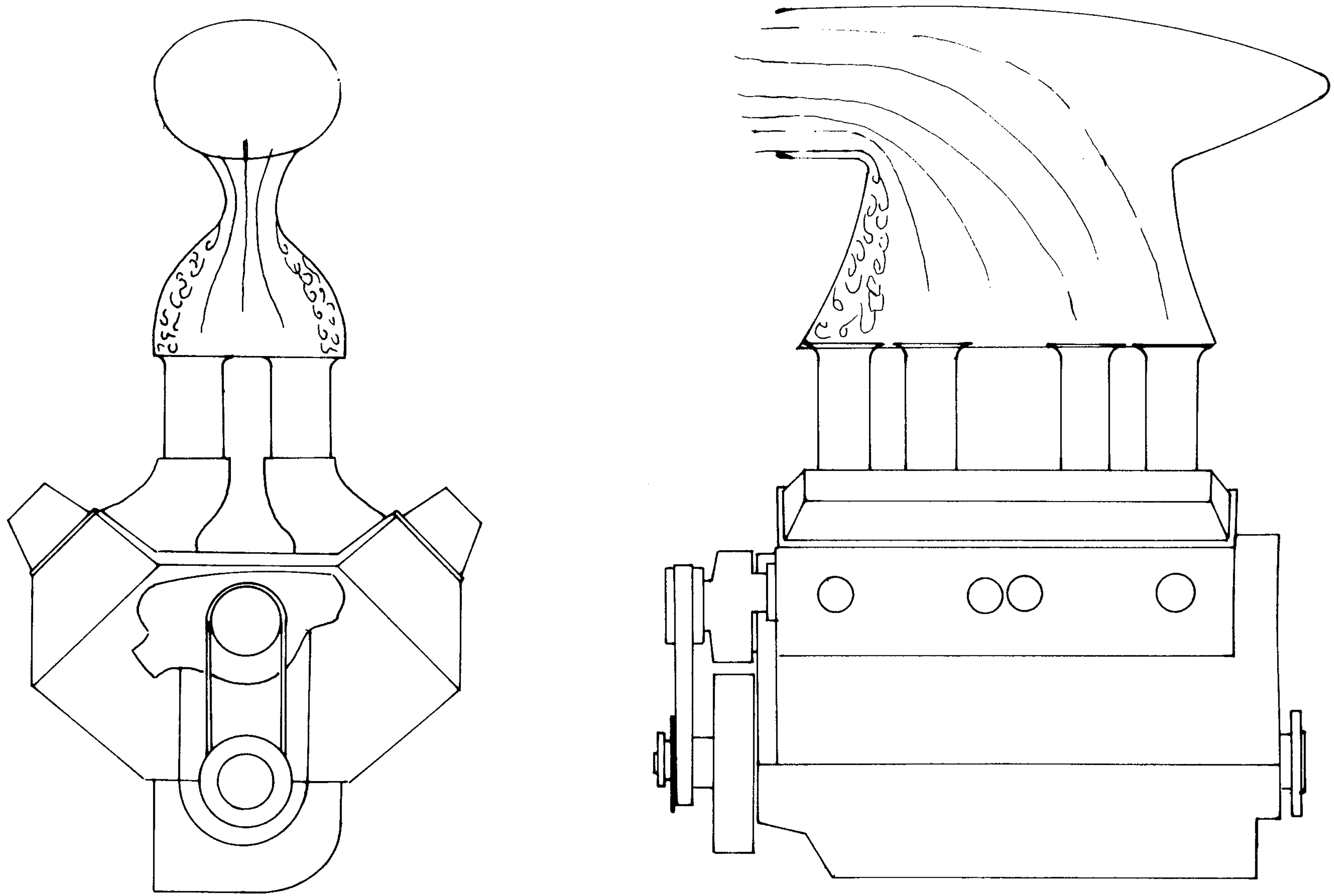

Figure (66a): Inefficient engine inlet cold airbox with poor diffuser design showing flow separation from walls.

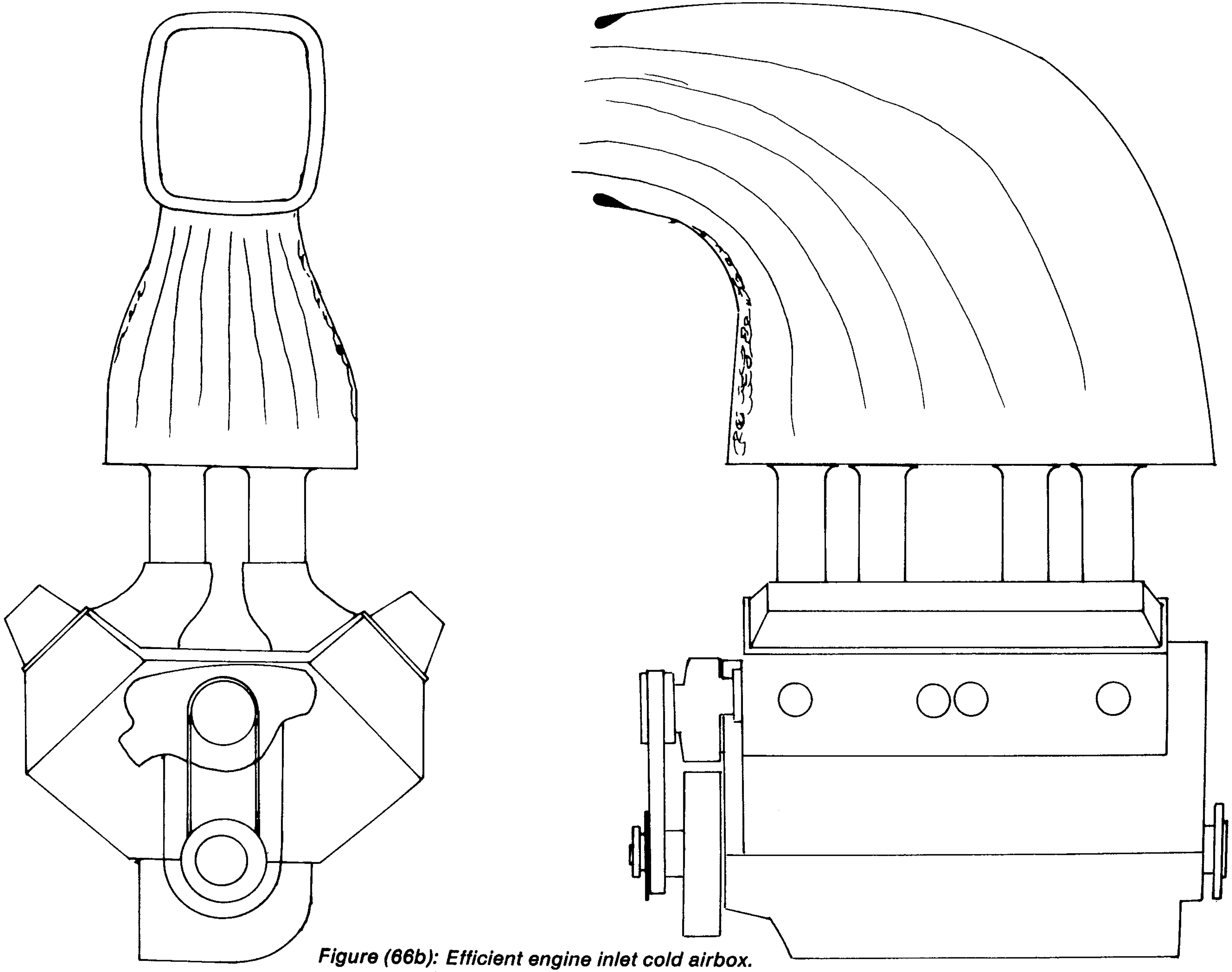

Figure (66b): Efficient engine inlet cold airbox.

First, the intake must have enough area to get a sufficient volume of air to the engine at low road speed when the ram doesn't work. Remember that airflow into the box varies with road speed while air required by the engine varies with rpm. We're not trying to ram at low speeds—we are merely trying to avoid choking the engine. A large enough inlet for low speeds probably means that we will over ram at high speed. The most common method of dealing with this situation is to depend upon leakage between the plenum base and the intake stacks or on small bleed holes in the plenum. I personally think that a spring loaded pressure relief would be tricky and I keep meaning to try it but never have. Along these lines, it is absolutely necessary, if you are using carbs, to make sure that the float chambers are seeing the plenum pressure. Otherwise your mixture strength is going to be so far off that the whole exercise will be hopeless. If the air box is really working it will also be necessary to supply more fuel to the engine or you will run lean—maybe even lean enough to burn a piston.

Next the edges of the intake opening must be well radiused to avoid partially stalling the inlet at high yaw angles. The intake must be so located that it cannot be blanked out by some other part of the vehicle at high yaw angles. It must also be served by high energy air which means out in the free airstream for a ram duct or in a laminar flow area with a strong positive pressure gradient for a NACA duct. Be very sure that your intake is not picking up the heated air exhausting from a heat exchanger duct—you want the coolest air you can find—which means that you want the intake as high as you can get it.

If the inlet bit is straight forward, the diffusor/plenum isn't. The purpose here is to persuade the airflow to turn ninety degrees as smoothly as possible and to provide an expanding chamber in which the velocity component of the airstream energy will be converted to pressure which will be equal at each intake stack. We also have to avoid turbulence at any of the intakes.

We don't have a lot of room in which to accomplish this—particularly with large V-8 engines. Figure (66a) shows how bad things can get and Figure (66b) shows how to do it right. Theoretically the plenum should clear all of the intake stacks by at least 1/2 stack diameter and a full diameter would be better. This is sometimes a bit difficult to achieve. It is probably more important to get the shape right and to keep the last six to eight inches of the vertical walls vertical. The plenum base must be sealed to the intake stacks and this is usually done by the simple expedient of setting the base on top of the stacks and sealing with foam or rubber grommets. There is a theory that the stacks should extend into the plenum chamber to minimize turbulence but it doesn't seem to make any practical difference.

Speaking of the inlet stacks, any basic air conditioning book informs us that for maximum undisturbed flow the lip of an inlet stack should have a full radius. For some reason only Cosworth, Ferrari and Porsche seem to have caught onto this simple fact.

The outside shape of the airbox/engine cover is a question of minimizing drag and interference with the rear wing. With a high box we can actually improve the airflow to the wing. Again there is pretty general agreement about what shape will do the job and looking at current photos will get you up to date with the state of the art. With a high air box—as on a Can Am car, it is possible to bleed off some of the air to cool the magneto or the rear brakes. Some sort of rock screen should also be employed and you should make very certain that the whole thing is securely enough attached that there is no possibility at all of its coming off.

In keeping with my self-imposed practice of assigning some basic numbers to the features under discussion, let's see just what the ram aspect of the air box adds up to:

$$\text{Intake Ram (psi)} = \frac{\text{Air Density (lb/ft}^3\text{) x (Air Velocity in fps)}^2}{288g}$$

$$\text{At 80 mph—Intake Ram} = \frac{0.076 \times (118)^2}{288 \times 32.2} = 0.11 \text{ lb/in}^2$$

$$\text{At 160 mph—Intake Ram} = \frac{0.076 \times (235)^2}{288 \times 32.2} = .45 \text{ lb/in}^2$$

In both cases we have assumed a 100% efficient duct, which is not possible—75% efficient would be a good one. So the figures become 0.083 p.s.i. and 0.34 p.s.i. respectively. They don't sound like much—and they aren't—in the quantitative sense. But a gain of 0.34 p.s.i. inlet pressure is a percentage gain of 2.3% over standard atmospheric pressure—which is worth talking about.

If we can manage to grab cooler air for the inlet system through our box than it would otherwise receive, then we will gain 1% in air density for every 3° F. that we cool the air—yes, that is why turbos and superchargers use intercoolers on the inlet side.

The largest gain in engine performance, however, will come from the even distribution of inlet air to the individual intake stacks that is provided by a well designed and efficient plenum.

My last word on airboxes is that they work. They work on any type of race car and they work with either carburetors or fuel injection. They only work if they are correctly designed. It is worth taking the time and trouble to make a good one.