Duct System Losses Are Total Pressure Losses

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Confusion in the use of the terms STATIC PRESSURE and TOTAL PRESSURE is widely prevalent among HVAC Engineers and Contractors. There are serious consequences of not distinguishing clearly between the two, and one example would be that you make troubleshooting more difficult and in some cases impossible. Take a careful look at Figure-1 below.

If you send out an Air Balance technician and ask him, "What kind of static are we losing between points 0 and 1, and points 2 and 3?" You are guaranteed to get bad information back. (Unless your Company is among the lucky few, where the Technicians are smarter than the Engineers.) You have phrased your question incorrectly and you, not the Technician, are responsible for the garbage readings returned from the jobsite.

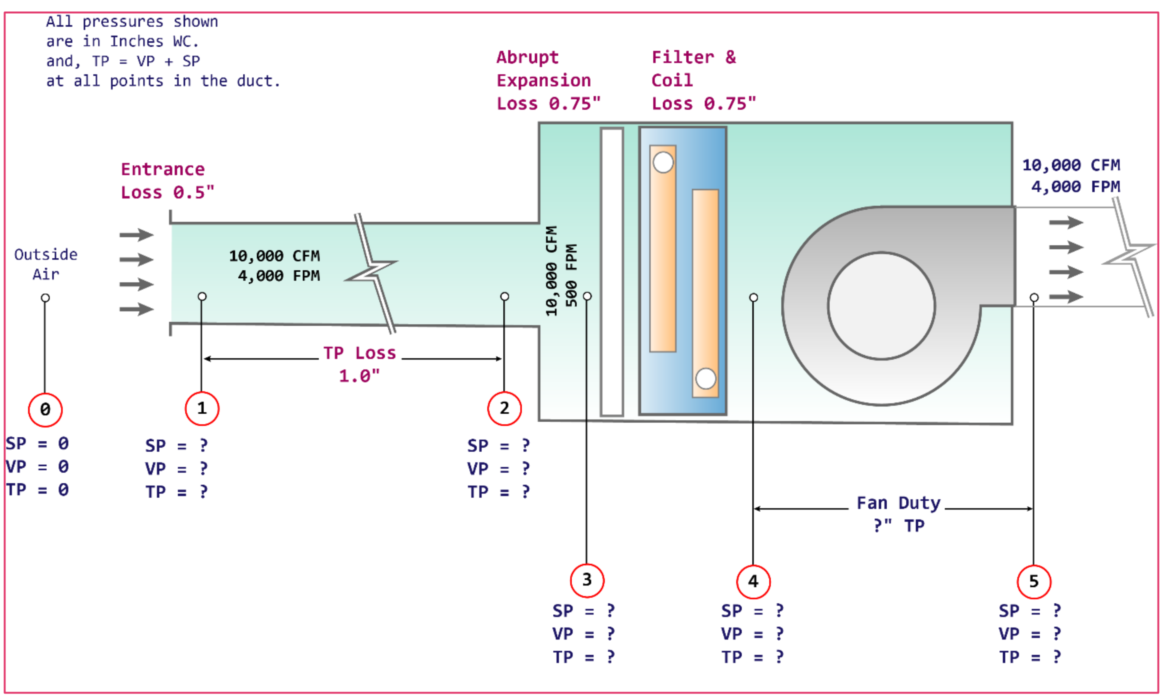

FIGURE-1

We have designed this layout for some industrial cooling system which is not working as designed and we are forced to send a technician to see where the problem might be. Before going to the jobsite to take the readings, the technician asks you, "I know the flow is given as 10,000 cfm, but what kind of pressures should I expect to read at points 1 through 5 marked on the sketch?" That sounds like a reasonable request, after all he cannot figure out what is wrong, if you don't tell him what is right. You say to him, "Let me work out the numbers and I will email them to you shortly."

Can you quickly fill out all the pressures marked with "?" in the Figure?

(All engineering drawings of Air Handlers and general Fan Systems should have a "Pressure Profile" detail as shown in the Figure. (Note that I said "Pressure Profile" not "Static Pressure Profile".) It is an invaluable troubleshooting tool when the system is not performing as intended.)

You start with reminding yourself of the very fundamental air flow relationship:

Total Pressure = Velocity Pressure + Static Pressure
TP = VP + SP

(For the purpose of this Post, we will assume that you have already calculated the pressure losses from the ASHRAE or other reference books and these have been listed in red in Figure-1 above.)

Now you take a copy of the Figure-1 page and start filling in values for points 0 through 5 like this:

Point-0 (Free Atmosphere)

SP = 0
VP = 0
TP = VP + SP = 0 + 0 = 0" WC

Point-1 (Just past the duct entrance.)

You had looked up ASHRAE or some other handbook and calculated the entrance loss to be 0.5" WC.

Next, if we know the air velocity, the velocity pressure is calculated as:

$VP = (V \div 4000)^2$ where V is the air velocity in FPM.

(Note: SP can be +ve or −ve. TP can be +ve or −ve. VP is *always* positive, unless of course, the air flows backward through the fan or due to some space-time warp, time starts to flow backwards.)

So you proceed as follows:

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SP = 0 - 0.5”           = -0.5”     (Pressure drop at entrance.)
VP = (4000 ÷ 4000)²     = +1”
TP = SP + VP            = -0.5 + 1 = +0.5”
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Wait! What? This should be a classic WTF? moment for you.

If you didn’t catch my stupidity above — you need to read and digest this Post very thoroughly or your career as a HVAC designer will be very short lived!

What have I done? They are reporting blood-curdling screams coming out from under a grave in Basel marked “Daniel Bernoulli”! I have also defiled the most sacred tenet in all of fluid mechanics: “S#!t flows downhill!” Do you see that the pressure at Point-0 was zero (atmospheric) and the TP at Point-1 is +0.5”. How can air go from a point of low pressure to a point of high pressure without any mechanical device between the 2 points? Clearly there is something very rotten in our proceedings above.

What I did wrong above happens a lot more than it should; and during troubleshooting it fools HVAC Engineers and Technicians into conclusions that are totally erroneous.

In order to learn to do it the right way you must first put your right hand on your heart and repeat the following LAW after me:

“ALL DUCT SYSTEM LOSSES, (FRICTIONAL OR DYNAMIC) ARE TOTAL PRESSURE LOSSES. STATIC PRESSURE HAS NOTHING TO DO WITH IT.”

(I am not sure how or why this confusion started in our industry, but all current handbooks, ASHRAE in particular, take great care to indicate system loses as TP loses.)

All elements of a duct system like the ductwork itself or elbows, transitions and dampers etc. cause a drop in Total Pressure. On the other hand, depending on the geometry of the element, the

Static Pressure may go up, down, or stay the same. We will see this below in working our example.

Now let us re-work the above 2 locations correctly. Actually each of the first 4 marked locations in the sketch will be evaluated in a similar manner as follows:

1. The TP at any downstream point will be less than the TP at its corresponding upstream point by the amount of friction and dynamic pressure loss between the two points. In other words:

   $TP_{n+1} = TP_n - (\text{Friction} + \text{Dynamic Loss})$
   between any 2 points (n) and (n+1)

   (Don't let the subscripts intimidate you here, all I am saying is that the loss between any 2 points is the difference between their TPs.)

2. The VP will be calculated as: $VP = (V \div 4000)^2$. Always positive.

3. The Static Pressure will be calculated as (TP - VP = SP). Same equation as above, just rearranged.

This 3-step procedure may look simple, (and it is) but you will be surprised how many Engineers get tripped up - even Manufacturers.

Luckily most commercial HVAC applications have low and roughly constant velocity through the system and the error of mixing SP with TP goes unnoticed.

Now look at Figure-2 below which has the correct values worked out.

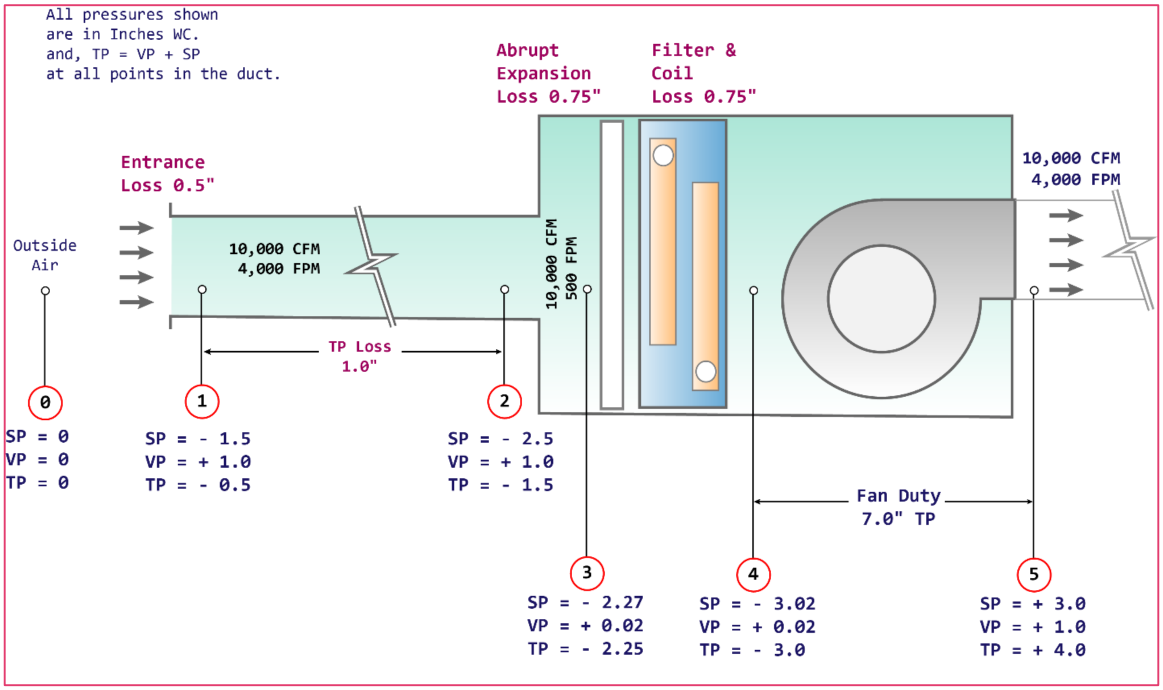

FIGURE - 2

I will work out Point-1 here and you can check the rest yourself to see how it is done.

$TP_1 = 0 - 0.5''$ $= -0.5''$ (Entrance Loss, like all loses, is a loss of TP)
$VP_1 = (4000 \div 4000)^2$ $= +1''$
$SP_1 = TP_1 - VP_1$ $= -0.5'' - 1'' = -1.5''$

As a check we see that TP = VP + SP or (-0.5″) = (+1″) + (-1.5″)

Note that the (-0.5″) Entrance Pressure Loss is *not* the same as ($SP_0 - SP_1$).

Hopefully you will get this sheet filled out, like in Figure-2, and send it to your air balance ace in time. If not there is a good chance you will get a phone call something like this: *"I think I have found out what is wrong … that damn entrance duct design is no good … we are losing 1.5″ of "static" right of the bat."* And yes, he is right, the duct entrance design can be improved; but it is NOT losing 1.5″ of Pressure. In fact if he reads -1.5″ static at the duct entrance, you should be delighted; things are going per plan – the trouble is elsewhere. I leave it up to you to look at the data and explain to your field tech. what is going on.

The calculation for the rest of the points (except Point-5) follows the same 3-step format. It has been done in Figure-2 and I will not repeat it here. But at each location there are some interesting observations and let us look at those and see what we can learn:

Point-2

The Total Pressure loss is 1.0″. This is the loss in the duct and any fittings between points 1 and 2. Here the point to note is that the velocity at Point-1 is the same as the velocity at Point-2. It is because of this special circumstance that the change in Static Pressure is the same as the change in Total Pressure. In this special case you can get away by (incorrectly) calling duct and fitting loss as Static Pressure loss.

Point-3

This is perhaps the most interesting point and brings out the concept I am trying to drive home. The abrupt expansion loss is 0.75″. This is clearly shown as a TP loss. Look at the SP value – it actually INCREASES! The velocity has gone down from 4000 FPM to 500 FPM and the Static Pressure has increased from -2.5″ to -2.27″. (Just a simple consequence of Bernoulli's relationship (SP + VP) = Constant.)

The minus signs might obscure this fact a little but converting to absolute pressure leaves no doubts. In absolute pressures (taking 407″ WC absolute as 0″ WC gage) we have Point-2 SP at 404.5″ and Point-3 SP at 404.73″. An increase of 0.23″. *This conclusively shows that it is the Total Pressure that is lost, the Static Pressure may go up or down depending on the downstream velocity.*

Point-4

The velocity stays constant at 500 FPM between Points-3 & 4. Therefore, the Filter and Coil pressure drop of 0.75″ shows up equally in TP and SP drop.

Point-5

Point-5 has been filled out based on the knowledge that supply duct portion of the Total Pressure loss is 4.0″. Then if the duct is sized such that the outlet velocity is 4,000 FPM then the Static Pressure at the fan outlet has to be 3.0″.

Fan Duty

The fan has to take the air from (TP_4 = -3.0″) to air at (TP_5 = +4.0″) a total TP of 7.0″. *So the fan has to be selected for 10,000 CFM @ 7.0″ TP.*

A BIG NOTE OF CAUTION HERE. The static pressure rise through the fan:

(SP5 – SP4) = (3.0″ - (-3.02″)) = 6.02″,

is NOT the same as "Fan Static Pressure".

If you are not sure about this, read my Post on this Website series titled:

"The Curious Definition of Fan Static Pressure". Ω