# What is air track?

## 1 Introduction

The SAHF model was thought up by Australian Shan Raffel in the early 2000's. After much debate with colleagues, and under the influence of American Ed Hartin the model changed somewhat later into B-SAHF. This model has also been called "reading the fire". It's a tool to determine what kind of fire one is dealing with on the fire ground. B-SAHF stands for Building, Smoke, Air track, Heat and Flames. The goal of this article is to elaborate on the parameter: air track.

## 2 Air track

### 2.1 Why does smoke flow?

#### *2.1.1 Buoyancy or Archimedes' principle*

Flow theory is very complicated. A lot of physical parameters are involved. Here we will try to describe what is happening during a fire.

During a fire a crucial role is played by the seat of the fire. The seat of the fire produces hot smoke. This smoke is hotter than the surrounding air. Everyone knows that when objects are heated up, they expand. For solids and liquids the expansion is rather limited. On the contrary, for gases (smoke) the rise in temperature causes a massive expansion. Because of this expansion, the density of the gas decreases. This means that the weight of 1 cubic meter of gas will decrease. Smoke that has a temperature of 315 °C has a density that is equal to half the density of air at 20 °C. An increase of temperature causes a decrease of density.

So what is the importance of this difference in density? To understand this it is necessary to perform a thought experiment. Think of a tub with water in it. Take a ping pong ball and hold it down at the bottom of the tub. Now release it. The ping pong ball will rise to the water surface. The reason for the ball's rise is a difference in density. The water exerts an upward force onto the ping pong ball. This is called Archimedes' principle. The upward force is directly proportionate to the volume of the ball and the difference in density between the ball and the water. Seeing that the ping pong ball is much lighter than the water it is in, it will rise.

Because of the fact that smoke has a lower density than the surrounding air, smoke will rise. While smoke is rising, air is being mixed into it. This causes the temperature of the smoke to drop. Because of the drop in temperature, the difference of density also decreases. And subsequently the buoyancy will decrease as well. From the moment the smoke has cooled down to the point where its temperature equals that of the surrounding air, it will stagnate. One can sometimes observe this phenomenon in room that is filled with people smoking cigarettes.

Unlike the ping pong ball we are not dealing with a single particle of smoke, but rather a continuous flow of smoke. And unlike the tub there is no water surface. Here the air's boundary is made up by the ceiling. The smoke will therefore be unable to rise indefinitely. We could look at this as if we were to release dozens of ping pong balls at the bottom of an aquarium. After a while the balls arriving at the ceiling will push aside those already there. The same thing occurs in a flow of smoke. The smoke will flow up to the ceiling, will then divert and flow horizontally along the ceiling.

### *2.1.2 Difference in pressure*

Another way of examining air track is by looking at the difference in pressure between two areas. A well-known example of this is a dam. A dam is constructed to achieve a higher water level on one side and a lower one on the other side. Because of this the pressure on one side is also greater than on the other. Beneath the surface a duct can be opened to allow water to flow from one side to the other. Water will always flow from the high pressure area toward the low pressure area. The flow is trying to nullify the difference in pressure. The flow will also continue until there no longer is a difference in pressure. The bigger the difference in pressure, the more violent the flow will be.

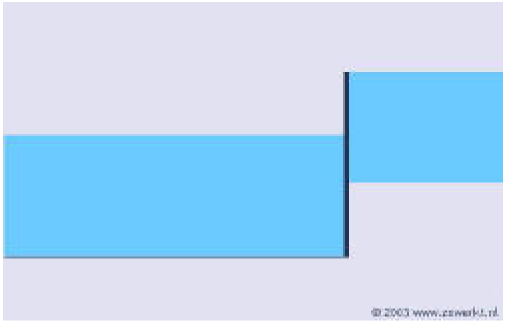


**Figure 1** Schematic drawing of a dam.

The same phenomenon occurs when dealing with gases. The breathing apparatus (BA) is a well-known example of this amongst fire fighters. Inside the BA bottle air is being held at a pressure many times more than that of the surrounding air. When the BA is opened an exit becomes available from which the excess in pressure can escape. Air is being blown out. This produces a lot of noise. The air is flowing rather fast. This is because of the big difference in pressure between the air inside the BA and the atmospherical air pressure outside. The gradual escape of air from the BA will cause the pressure inside to decrease. The speed of the air flowing out will drop and the noise will subside. However the flow of air will continue until the BA air pressure equals the outside pressure. When during a fire an overpressure is created in a certain area, a flow of air (air track) will be created when an opening is made. Nature will try to eliminate the difference in pressure.

## 2.2 What happens next?

Further development will depend of the size of the fire. If the fire grows and expands, the amount of energy released increases. In that case the amount of smoke produced also increases.

Karlsson & Quintiere describe fire development in their book "Enclosure Fire Dynamics". The description is rather schematic, but it's a good approach to the real thing. Being described are four different pressure profiles which a fire exhibits from incipient to fully developed phase. During the incipient phase of the fire an overpressure is being created inside the compartment by the smoke. The smoke that's being produced will expand. This process is being hindered by the air present in the surroundings. This causes a slight excess of pressure. If an opening were to be made, the pressure could be relieved.

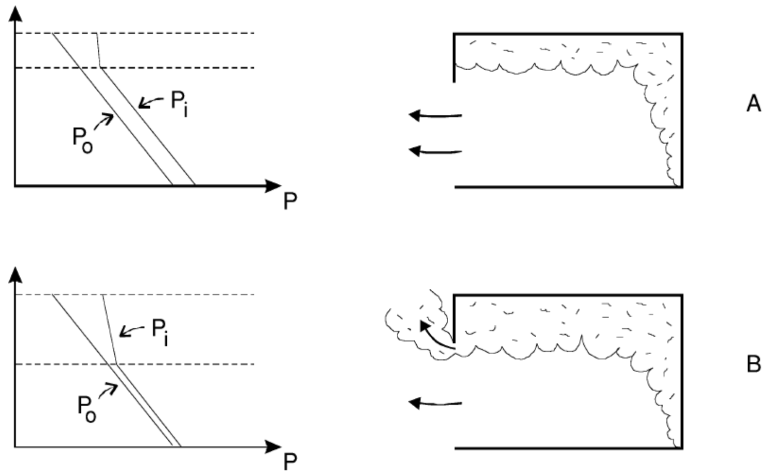


**Figure 2** Pressure profiles A and B. *(Graph: Karlsson & Quintiere)*

Figure 2 , A depicts the situation at the incipient phase of the fire. The seat of the fire is producing smoke. The smoke will rise and form a layer up against the ceiling.

The fire will create a slight excess of pressure. Because of this part of the colder air inside the room will be forced out. To the left of this drawing a diagram depicts the pressure profile. The horizontal axis indicates the pressure. This means the pressure increases toward the right. The vertical axis indicates altitude. The line labeled $P_o$ represents the outside air pressure. The air pressure is made up by the weight of the air on the earth. The higher one goes, the thinner the air gets. The air pressure decreases. The inclination of the line is obviously exaggerated, but this serves the purpose of illustrating the phenomenon more clearly. The pressure inside the compartment is represented by the line labeled $P_i$. The graph shows that the pressure inside is a little bit higher than outside. The line $P_i$ is located more toward the right hand side. What's also clear to see is that this line runs largely parallel to line $P_o$. The air inside the room more or less has the same temperature than the air outside. In that case the pressure also decreases equally according to the altitude. The moment on which $P_i$ touches the smoke layer inside the room, the line diverts. The temperature of the smoke layer is a lot higher than the temperature of the surrounding air. The density of the smoke is therefore lower. This means that smoke weighs less than the surrounding air. If one were to rise in such an environment, the pressure will decrease less rapidly.

As the fire grows, several things will happen. The smoke layer will drop. This means that the moment on which $P_i$ diverts will also be positioned lower. The overpressure will decrease because air is being forced out through the opening of the door. The line $P_i$ will slide towards the left and will be positioned closer to the line $P_o$. The latter still represents the outside air pressure. This line will remain unchanged throughout the entire fire development. Simply put it's not because there's a fire, there's a change in atmospherical conditions.

Subsequently a second pressure profile is being created the moment the smoke layer drops below the height of the door opening. This pressure profile is called profile B and lasts only for a few moments. At this stage both cool air and hot smoke are flowing through the opening of the door. This swiftly causes the elimination of overpressure inside the room. This is a kind of transitional phase that is only necessary to allow for understanding of the following development.

## 2.3 The development phase and the fully developed fire

The fire has reached the development phase. The smoke layer has already dropped severely. The temperature of the smoke has increased by a lot. The seat of the fire is consuming a substantial amount of air. The air inside the room is no longer sufficient to feed the fire. Air is being drawn in from outside to feed the need of the fire. Pressure profile C will be created.

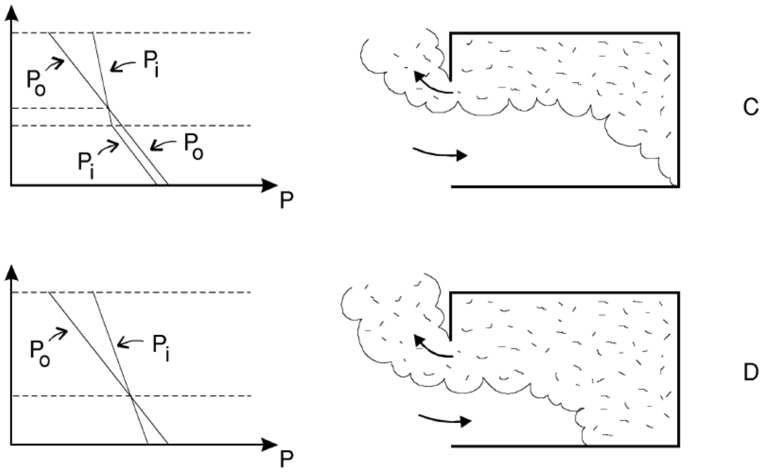


**Figure 3** Pressure profiles C and D *(Graph: Karlsson & Quintiere)*

The line $P_i$ (air pressure inside) is moved further toward the left. The line has moved so far that air pressure at ground level outside now is greater than the air pressure inside.

Because of the smoke layer dropping even further, the line now diverts even closer to ground level than in profile B. Two separate zones can now clearly be distinguished. The zone underneath the smoke layer in which the temperature roughly equals the outside temperature. In this zone both lines will run parallel. The air pressure will decrease equally according to the altitude because the density is the same. Because of the fact that the inside pressure is less than the outside pressure, an air track from outside to inside is being formed. This is the flow of air (air track) feeding the fire.

The second zone is being formed by the smoke layer. Inside the smoke layer the line $P_i$ diverts. This means that the difference between the inside pressure and the outside pressure is decreasing. At a certain point the line representing inside pressure ($P_i$) intersects with the line representing outside pressure ($P_o$). At this point the inside pressure equals the outside pressure. This is called the neutral pane. Typically the neutral is located about 10 cm above the bottom of the smoke layer. This distinction is of little importance to fire fighters. In practice the bottom of the smoke layer serves as a good indication for the neutral pane.

Above the neutral pane both lines continue along their respective paths. This causes a new difference in pressure to be created between the inside and the outside. Pressure inside the room is greater than the pressure outside. This difference in pressure increases in relation to the altitude. The higher above the neutral pane, the bigger the difference in pressure. This is not the case below the neutral pane. There the difference in pressure remains constant for every altitude. Above the neutral pane a flow of smoke will be created. The speed at which this flow travels, increases when the smoke gets hotter and when it rises higher above the neutral pane. During pressure profile C there is a flow inward (air track) of fresh air below and a flow outward of smoke. This profile will be maintained up until flashover. The time needed for this to happen, depends on the fuel load and the specifics of the compartment. As mentioned in previous articles, this time period has shortened considerably during the past decades. The time frame for flashover to happen now typically takes 3 to 4 minutes. Experience has shown us that the spread of the fire fuel inside the room or a lack of oxygen as a result of a too small of an opening, can both cause flashover to become delayed.

**Figure 4** Double flow for a compartment fire. Smoke is flowing out from the top of the door opening. Air is flowing in from the bottom. *(Photo: Nico Speleers)*

After flashover there are no longer two separate zones with different temperatures. The compartment is considered to be a single zone with approximately the same temperature across the entire room. There no longer is a definable smoke layer. The bottom side of the openings are still used to draw in fresh air but the smoke layer that had been clearly distinguishable during the development phase, has now completely filled the compartment. On top of this, the smoke has ignited. Figure 3, D depicts the pressure profile of this phase. The outside air pressure $P_o$ is still unchanged. The pressure profile inside has taken a new form. Considering that the temperature inside is roughly the same across the room, the line representing this pressure no longer has a diversion. The temperature inside the room is much higher than outside. This means that the density inside is a lot lower than outside. This in turn causes the pressure to decrease less fast according to altitude. The point at which the 2 pressure lines intersect now indicates the neutral pane. At this point the inside pressure equals the outside pressure. Below this pane air will flow inward while above, smoke (and flames) will flow outward.

## 3 Practical?

The paragraph above describes pressure differences and how air track (flow) is created. Subsequently the different pressure profiles belonging to a compartment fire were discussed. It is possible to apply this knowledge practically while reading a fire. The path followed by the smoke from the seat of the fire to the outside is called the flow path. A good observation of the air track combined with knowledge on fire development can result in a large amount of information on the fire at hand. It is however important to realize that all this relates to small compartments. This means rooms under 70 m². Also the height of the ceiling may not exceed 4 meters.

### 3.1 Height of the smoke layer

The height of the smoke layer tells us something about the level of development of the fire. If there’s just a smoke layer at the ceiling, the fire is probably still at the incipient phase. However one can't be 100% certain of this either. It may well be possible that a ventilation outlet is present somewhere up high. This will then influence the normal display of the smoke.

If however the smoke layer has reached a thickness of about 1 meter, the fire has reached the development phase. Recent studies have shown that the time needed for a ventilated fire to reach flashover, is approximately two to four minutes. As the fire develops further toward the point of flashover, the smoke layer will drop.

When the smoke layer has dropped down to 1 meter from the floor level, the fire will have gotten very close to the point of flashover. The evolution of the height of the smoke layer (and of the neutral pane which is located a little bit higher) is a good indicator that can be used to evaluate both the speed at which a fire expands and the risk for flashover.

### 3.2 Speed of the flows

The beginning of this article explains how a flow is created because of a difference in temperature. The bigger the difference, the faster the flow will be. When the smoke starts to flow very fast, turbulence will become clearly visible. By observing the speed of the flow it is possible to assess the intensity of the fire. An intense fire will produce more heat. This heat will lead to a bigger difference in temperature. This will then in turn result in a faster flow. It is therefore possible to deduce whether a fire is well developed or not from the speed of the flow. This is also an indication of the phase the fire has reached in its development.

### 3.3 Where's the fire?

The air track also teaches us something about the location of the fire. Smoke will flow away from the fire. When looking at the smoke it is possible to determine (maybe with the use of a thermal imaging camera) in which direction the smoke is flowing. If one were to follow the smoke upstream, the seat of the fire will be reached.

Aside from that the opposite can also be concluded: when a door is opened into a room and the smoke doesn't move, this will probably mean the room is (was) not linked to the room containing the fire.

Obviously it is also necessary to account for the possibility that one was not in the flow path before opening of the door. After opening the door a flow will start. This offers information on the location of the fire, but it is equally important to realize that this newly created air track will provide the fire with extra oxygen.

## 4 Bibliography

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