ANATOMY OF A BACKDRAFT

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V-2.00

«The fire of contents, and not of a container »

Introduction

Whilst it is common to see photographs or video clips of backdraft, rare are the examples of step by step analysis of the phenomenon.

That's what I propose to do in this document, on the basis of two videos, both taken on the technical training center of SDP2 Company, in France, in the department of Mayenne (53).

The room

The room, it is a box in 15 mm thickness agglomerate. This "room" is 35 cm in depth, 50cm width and 60cm high. The discharge system (partly higher) and the ventilation of the frontage remain closed during the two experiments described in this document. The door, located at the front, is 25 cm in height and 20 cm width. It should be noted that opening is located in such manner that it is not in the axis of the hearth, which constitutes a characteristic of the mini-houses used on this technical training center (see photo on first page).

The fire

It is composed of a newsprint sheet, of a few small pieces of small cage and some cleats. It does not comprise any synthetic element of type foams or plastic. It is lit by simple ignition of an end of the newsprint sheet. Fire is not thus poked and develops naturally with the door and the discharge system wide opened. The "traditional" experiments are carried out during the phase of heating: test of heat of smoke, then closing of the discharge system for rising temperature of the high part of the room. The first backdraft is carried out approximately 12 to 15 minutes after lighting. They are the simple result of the ignition of the smoke, made up inter alia, (like all the smoke from fires) of CO and CO2.

Time unit

The video stills display up to 15 images per second. The notation thus leaves the principle that 3,8 means that we are at the 8th image after the beginning of the 3rd second. Thus 3,15 is equivalent to 4.

Vidéo 1 - Backdraft without wind

After a warming-up time of the volume of approximately 15 minutes, the backdraft was carried out in the open air, with no wind.

The video starts whereas the door has been just closed by the instructor.

Closing the door	
	**T = 0 sec.** Closing of the door. This one is relatively tight. It blocks the opening entirely, which is located in the left lower corner of the box, while the fire is sited in the back right corner of the box.
	**T = 1 sec.** The door is still closed. Fire generates more and more smoke and the pressure increases in the room. One notices it with the smoke which leaves in the form of plumes on the level the door. But at this step, smoke is grey.
	**T = 2 sec.** The pressure increases further, just like the quantity of generated smoke. We note that the smokes which escape from the door is denser, and of the fume also appear on the level of the small ventilation of the frontage. We can notice that this smoke is now white.

Opening the door	
	**T = 3 sec.** Overpressure in the room is significant. The door, open quickly, creates a depression which attracts smoke. However, hot smoke tending to rise supposes that a layer of smoke must also exist in the ceiling area.
	**T = 3.1 sec.** Continuation of the opening. The bulk of smoke "always follows" the door. This smoke is very charged (dark color at exit with the room) and a flow seems to fall from the ceiling.
	**T = 3.4 sec.** Overpressure seems to decrease, smoke starts to disperse. At exit of the room, it drops and the extracted quantity increases further.

	**T = 3.9 sec.** The "normal" exit of the smpoke, starts. The block of smoke, which seemed to stick to the door, always moves away in the same direction, while the general emission now continues upwards. It is noticed already that the bottom of the door does not contain much smoke, if any.

The wait	
	**T = 4 sec.** The extraction of the smoke continues from the upper portions of the door. The smoke is always rather charged, and becomes darker.
	**T = 5 sec.** The smoke changes aspect. Its seems more opaque but the quantity does not decrease. The air movement undoubtedly disturbs it.

	**T = 6 sec.** The mode of emission is stabilising: the smoke continues its exit by the top, and a movement of air is felt by the bottom of the door. This is correctly termed « gravity current ».
	**T = 8 sec.** The exchange becomes clear: the smoke leaves by the top, and one now sees by bottom a small zone of smoke whose slope shows that it returns in the room. It there thus well penetration of fresh air partly low and extraction of the charged smoke, partly high.
	**T = 9 sec.** The more the fresh air returns in bottom, the more the extraction seems to accelerate partly high. The smoke which leaves seems indeed a little more "projected" that with the preceding image.
	**T = 10 sec.** The position of smoke in the high part of the door, is from now on very clear, the lower part appearing completly empty.

This stage, we thus have a gravity current with exit of smoke by the top and entry of air by bottom. The fresh air, which returns, changes the mixture to some extent by diluting the gas, which at this stage is very concentrated and overheated: being too rich, it cannot take ignite. The fresh air gradually reduces the mixture below the upper flammable limit. The partly higher air flow causes the exit of the smoke, which balances volume. Placed in the opening, a firefighter would feel the fresh air to penetrate in the room, at the level of his legs, and would see this surge of air by the movement of the smoke on the level of the ground. The firefighter would also see the smoke escaping above him. It should be noted that the flow of fresh air, if it seems to move slightly to the top, does not move however directly towards the higher zone. It is normal, because the surrounding air with a temperature lower than the air and the smoke interiors. The fresh air is denser, it thus circulates partly low, arrives at the fire which heats it, then it goes up with the gravity current. It is what undoubtedly explains that the mixture is not diffused very quickly, contrary to what could occur if the draught "typed" directly in the very hot layer.

The « backdraft »	
	**T = 11 sec.** - The flow of smoke decreases, but seems to gain in power of exit. Only a kind of corridor of smoke remains present.
	**T = 11.7 sec.** - The flow of smoke starts to curve. It is the sign of an overpressure which has just created partly higher room.

	**T = 11.8 sec.** Beginning of the explosion. Partly high, the mixture drops below the upper flammable limit, because of dilution and the mixing generated by the air of the current of gravity: **it is the explosion**. Overpressure deforms the plume of smoke. It is noticed that the push comes well from the top of the box, the deformation of the plume tending to push this one downwards.
	**T = 11.9 sec.** The explosive phenomenon becomes extensive: its characteristic spherical form, starts to appear. One distinguishes part of smoke perfectly, below, proof that explosive energy pushes back smoke downwards and thus comes from the ceiling.
	**T = 11.10 sec.** The wave continues to advance, by forming a kind of sphere more and more.
	**T = 11.11 sec.** The sphere reached its high limits of size. It is formed perfectly while flames are visible in the opening of the door. The characteristic "Wooooof" is heard.

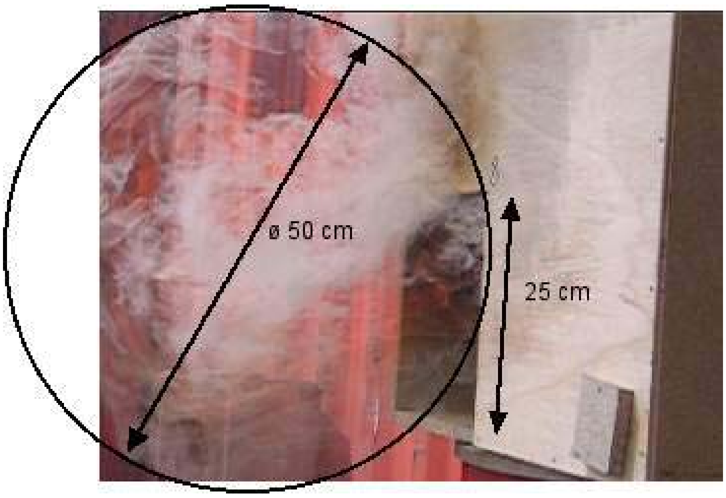
<table>
<tr><th colspan="2">After explosion…</th></tr>
<tr><td></td><td>T = 11.12 sec.
The explosion is finished. The remainder of smoke seems to disperse.</td></tr>
<tr><td></td><td>T = 11.13 sec.
The smoke continues to disperse. It is noticed that in this sequence, there is no resumption of fire. The phenomenon seems to have been exclusively explosive.</td></tr>
<tr><td></td><td>T = 12 sec.
The explosion made it possible for all overpressure to escape from the room, but it seems that this one is now at a lower pressure because the smoke now starts to turn over in the room, always aspired by the low part of the door.</td></tr>
</table>

T = 13 sec.
The aspiration continues. It's visible again as the flow of smoke is inclined, bellow of the door. At this stage, fire will begin again rather quietly, inside the room.

Evolution of the shape

This diagram shows the evolution of the shape of the smoke, since the beginning of the explosion until the end. One notices that the deformation is founded, not with a horizontal axis, but with an axis situated high-right towards low-left. The wave thus comes well the top of volume, where the concentration of gases was at their greatest, and/or originated the explosion.

The volume



Volume oh the box

$V = L \times H \times P = 0,47 \times 0,57 \times ,035 = 0,093765\ m^3$

Volume of the spherical wave of explosion

$V = 4/3 \times PI \times r^3 = 4/3 \times PI \times 0,25^3 = 0,065449\ m^3$

First analysis: overpressure.

It is obvious there is a significant overpressure in the room. This is contained at a certain time, a volume of 0,093765 m3 + 0,065449 m3 for a container of only 0,093765 m3. This in spite of the fact that a significant quantity of smoke escaped during time from opening from the door.

Second analysis: relative dimensions of the sphere and the room

Relationship between interior volume and the sphere:

$0,093765 / 0,065449 = 1,4326\ m^3$

Let us imagine that we have a 4 m x 3 m width and 2,50 m height of ceiling, therefore a small room. We obtain a total volume of:

$V = L \times H \times P = 4 \times 2,50 \times 3 = 30\ m^3$

By applying the same report/ratio, we obtain a "potential" explosive sphere of:

$V\text{-Sphère} = 30 / 1,4326 = 26,48\ m^3$

Let us calculate dimensions of the sphere which would contain this volume:

$V = 4/3 \times PI \times r^3$

So:

$r^3 = V / (4/3 \times PI) = 26,48 / (4/3 \times PI) = 26,48 / 4,18879 = 6,3216\ m$

So, r = cubic root of 6,3216 = 1,84902 m

Knowing that we have the ray, we deduce from it that the sphere will have a diameter of approximately **3,70 m.**

On the video, the sphere exceeds downwards: the mini-house being on a support, nothing prevents the expansion of the sphere of explosion, under the level of the ground. In reality, this quantity of gas would be added to the higher part of the sphere, increasing the size of this one compared to firefighters, in front of the opening.

Moreover, we speak here only about one explosion which, even if it reaches rather significant dimensions, results however only from one extremely 'average' fire, without foam, without synthetic matter: the fire created in the mini-house is made up only of paper, with some small wood parts.

In the same way, this explosion is very "clean": no collapse, no projectiles. In reality, the damage is largely higher, to quote only the roof of the Lutherien church St John which raised of three meters before falling down, following a backdraft (USA, February 2004).

A fire in an office or shelters of garden...

By carrying out the same type of calculation, while preserving the assumption of a very simple fire, the explosion resulting from a room of the office type of 10 m X 10m X 2,50 m (several compartments etc.) might generate an explosive sphere of:

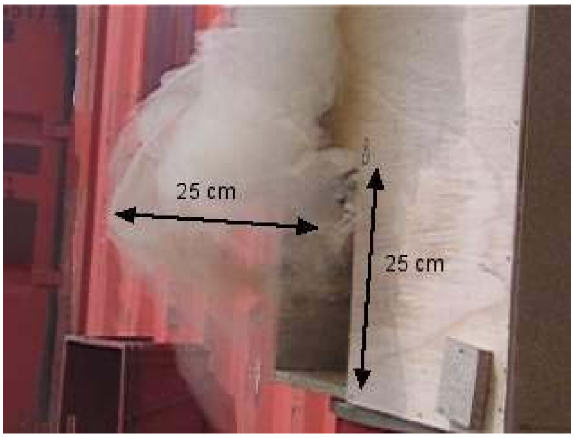
r = cubic root (10x10x2,5) / (4/3xPI) = 3,90 thus meadows 8 meters in diameter, is more than 3 stages...

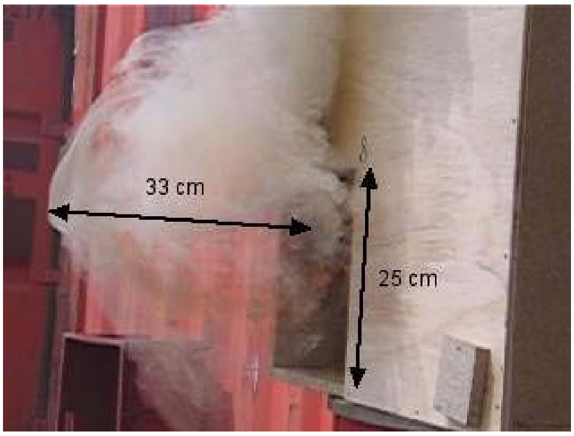
At the other end, a fire in a garden shed of 1 m X 1,50 m out of 2,50 m in height, would nevertheless generate an explosive sphere 1,80 m in diameter, that is to say the height of a man, upright in the frame, and this with a fire resulting from a few pieces of wood.

The danger is thus quite real, and whatever dimensions of the room, even in the case of a very small room, the explosive effect largely exceeds what a man could support. The PPE of the firefighter and the provision of capable hose-lines are thus imperative, whatever sized room is approached.

Note: it seems that the calculation of the report/ratio of size between the room and the "sphere", even if it appears to give significant dimensions for this "sphere", is below reality. Indeed, released heat and the volume of smoke produced by a simple sheet of paper and a few small pieces of wood, are without common measurement with the thermal energy which the furniture of a dining-room or a bed-room could release.

The propagation velocity





The video sequence was filmed with a numerical material, ensuring a flow of 15 images a second. Knowing that the two images above are followed, we note a propagation of 33-25 = 8 cm in 1/15th of a second.
Thus a speed of 8 X 15 = 120 cm = 1,20 m a second. Even if we are far from the 20 m/seconds affirmed in certain documents, we are however at a speed much higher than that which a firefighter with BA can travel, which thus does not have any chance to escape if such a phenomenon occurs.

Evolution of the smoke

Progressively we note an evolution of the smoke. This evolution informs us about the activity of fire. At the beginning, the box was opened and fire ventilated rather well. The smoke which one sees on the first image is thus light. As of the closing of the box, they become more opaque but also more significant because the fire becomes under-ventilated. Then, they become white. The white smoke is the sign of pyrolysis, therefore of a fire which starts to be choked. At this time, the quantity of smoke is always significant. Then overpressure increases and the smoke leaves then more quickly. Then, with the opening of the door, we have initially the extraction of the white smoke, then this smoke becomes coloured because fire starts again with being oxygenated.

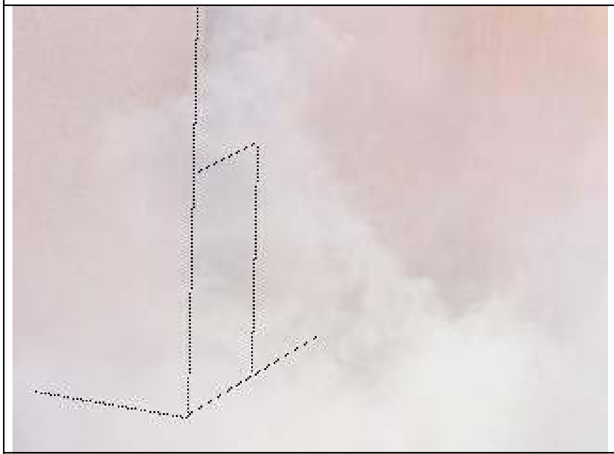
It is thus obvious that it is necessary to be very attentive with the quantity, the color, and the speed of the smoke.

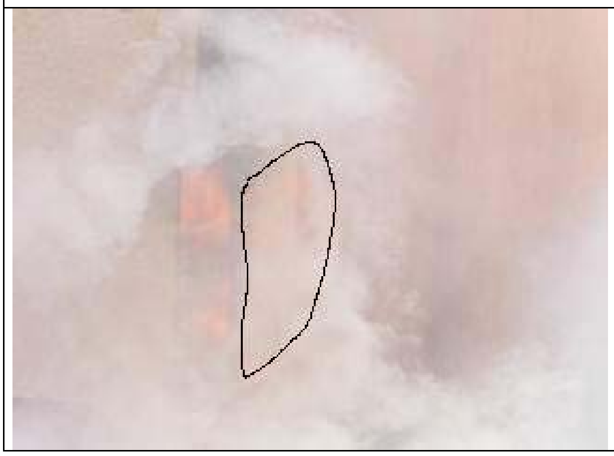
Vidéo 2 - Backdraft with string wind

In this second sequence, the room is strictly identical to the preceding case, just like lighting, the time of heating etc. Only two points are different:

1. The angle of sight, which will allow the observation of the restarting of fire
2. The wind, which blows in gusting wind, towards the opening.

The door was closed, then open. The gusts of wind prevent from distinguishing the shape and formation of the smoke and prevent from seeing the partly higher extraction and the air intake by the lower part.

The Wait…	
	**T = 5.14 sec.** The box is hardly visible, because smoke is strongly disturbed by the gusts of wind. Smoke is nevertheless rather intense, but it is difficult to determine if it is "heavy" or not.
	**T = 6 sec.** The time of an image and the fire is reactivated. The flames put fire at the smoke which strongly decreased.

The backdraft	
	**T = 6.1 sec.** Beginning of the explosion. The size of the flames inside the room is definitely higher, and one distinguishes a beginning from exit of these flames (delimited zone).

	**T = 6.2 sec.** The spherical form, typically becomes apparent. But contrary to the case studied previously, we have here a ball of fire and not only one wave of "overpressure".
	**T = 6.3 sec.** It is truly a ball of fire which is presented now at exit of the room. In terms of dimensions, this sphere is comparable with that of the preceding case. Only its composition seems to differ: less smoke, more flames.
	**T = 6.4 sec.** Beyond this explosive sphere, the effect seems followed more by an arrival of "consistent" flames. Either these flames really exist and follow the face of explosion, or it is a gust of wind which "generates them" by pushing back the face of flames. Difficult to determine at this stage. In any case, the firefighter thinking of dealing with simple resumption of the fire, will be in a very delicate situation.
	**T = 6.5 sec.** The production of a zone of "consistent" flame more behind of flow, seems to be confirmed. It is certainly the sign of a resumption of fire in the room.

	**T = 6.6 sec.** The "explosive" zone is now in its final phase. Flames leave directly via the door. They are bent back by the wind, but their dimensions remain significant.
	**T = 6.7 sec.** The disappearance of the "explosive" zone continues, while the recovery in the room does not seem to weaken.
	**T = 6.8 sec.** Despite of the wind which pushes back the flames, the spherical zone remains visible, proof of the force of the explosion.
	**T = 6.10 sec.** We arrive now in a simple resumption of the fire.

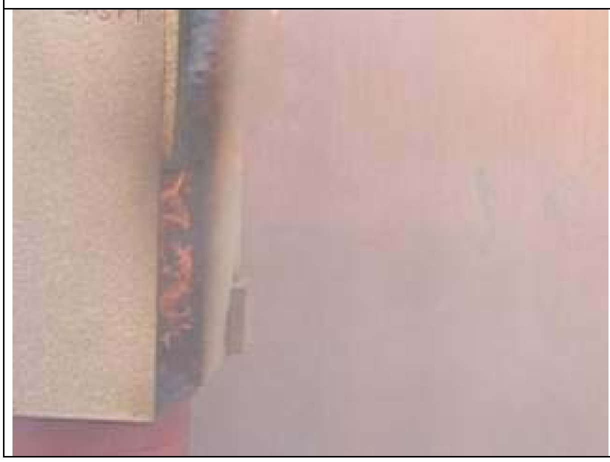
	**T = 6.13 sec.** The flames remain however disordered, and we notice that the zone of fire located in the room, is more "weak" that this same zone at T=6,3 for example.

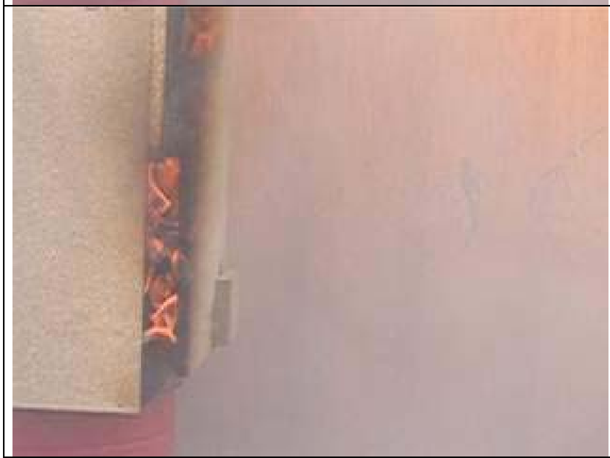
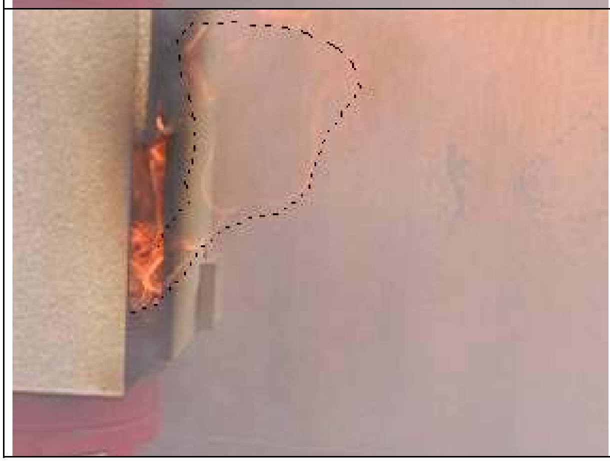
The explosion is finished. We can thus think that we will arrive during one time of resumption of the fire. Oddly, we will note that this recovery, which seemed very violent, in the final analysis will slow down gradually...

A few moments of calm ...	
	**T = 7 sec.** We are at the time hinge between the end of the explosion and the development of the supposed "recovery".
	**T = 7.5 sec.** We note that the recovery persists, but already the intensity of the flames, in the room, seems to drop.

	**T = 7.14 sec.** This reduction is confirmed, while smoke becomes again more present, while being diluted enough. In such a situation, the visibility is tiny.
	**T = 8.6 sec.** "diffuse" smoke is always present, and we see reappearing a small vertical smoke in top of the door, while the recovery rather seems to be transformed into fall of mode.

The wind can poke fire. But in our example, the too great force of the wind seems on the contrary to oppose the resumption of fire. This one had started to begin again following the explosion. This explosion served certainly as "rampart" with the violent wind, but once the finished explosion, the wind started again to be engulfed in the room, forcing fire to drop in mode. This fall of mode is accompanied obviously by a significant production by gas and fume, which remains in the room, in spite of the opening.

New recovery!	
	**T = 8.8 sec.** Even if the quantity of smoke is different, we find ourselves here in a situation nearly identical to that of dry T=6! Fire begins again of one blow inside the room.

	**T = 8.9 sec.** Its recovery is confirmed, with already appearance of small flames in top outside the room.
	**T = 8.11 sec.** The recovery continues, with now a fire whose consistency does not mislead, the more so as the presence of external flames, projected by the fire to the top of opening, is also confirmed.
	**T = 8.12 sec.** The flames again start to leave. We are again in an explosive phase, undoubtedly less impressive than the first, by the least a little different accumulation of gas and of the gusts of wind.
	**T = 8.14 sec.** The flames continue to be reconstituted outside. Knowing that the gusts of wind are always present, we well again have an overpressure which forces the flames to leave, counters the direction of the wind. At the interior, the fire continues to take consistency.

	**T = 9,2sec.** The phenomenon does not weaken. Worse, the flames which were only spread partly high opening, now start to be spread partly low, under the effect of this new breath.
	**T = 9.4 sec.** A new backdraft is occurring: the face of flame leaves again on all the height of the opening.
	**T = 9.6 sec.** Even if the form is less precise than during the first explosion, we have well here a significant production of a face of flame, while with the back of this face of flame, we perceive the same "thick" flame as we had seen in T = 6.5 sec. The wind manages to oppose the flames, just at exit of the door, but cannot fight against the projection of the face.
	**T = 9.8 sec.** The spherical zone appears slightly, the face of flame is very significant. We are unfortunately with the last image of the video, but we observed, without any possible doubt, a double backdraft.

High-Pressure Backdraft

We are certainly close here to a a kind of 'high-pressure backdraft' such as very well described by Paul Grimwood: a strong wind, directed towards opening, prevents the exit of gases and compresses those inside the room. The explosion can start by the opening of one door, but the explosion is very dependent on the wind, its direction and its intensity. The face of flame is very significant, as well in volume as in power.

We can think that the wind delayed the explosion, since the wind blows against thus opening against the direction of exit of the flames. However, even if it is difficult to judge with any precision, it seems that it is the reverse which occurs. Indeed, in the first video, we had a rather regular air flow, therefore a progressive mixing. There, we had a turbulent flow, therefore a faster mixing and explosion which arrives more quickly.

Moreover, even if the second video does not show the opening of the door, it starts nevertheless just after this opening. On the first video, the door is completely opened in T=4 and the explosion begins in T=11.7, that is to say 7 seconds + 7 images later. In the second case, the explosion starts 6 seconds after the opening of the door, that is to say 1 second and half earlier.

In the same way, we have an explosion more powerful than in the first case because of the principle of the turbo compressor: in the same volume the wind compresses fuel. There is thus to burn more in the same volume, the explosion is stronger. This explosion lasts also longer: from 11.7 to 11.12 in the video first thus 6 images, and from 6.1 to 6.10 in the first explosion of the second video, therefore on 10 images.

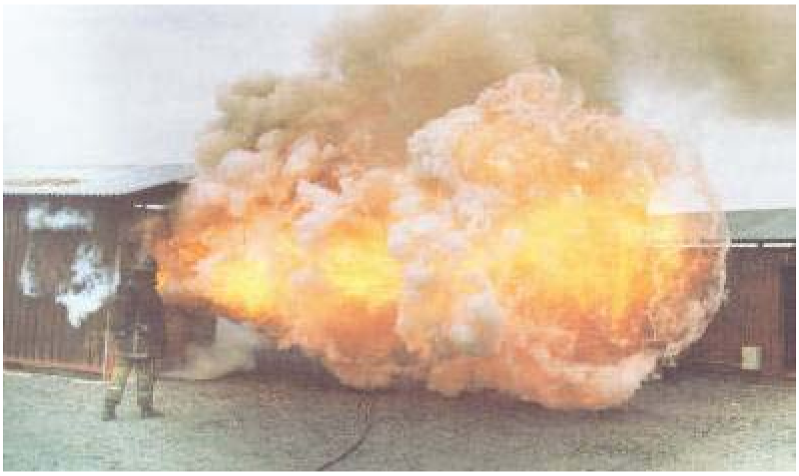
It should be noted that here, we have a strong wind, but that the opening which was made, therefore the direction of the explosion and the face of flame, is opposed to the direction of the wind. Let us imagine a short moment that we put one opening of more reduced size, vis-a-vis the wind, then that we opened the back of the box: not only we would have had the backdraft in all its violence as in this case, but in more we would have had a face of flame propelled at the same time by the explosion and the wind. It is what occurs when a firefighter opens the door of a room whose window is open vis-a-vis the wind.

Conclusion

Both backdraft studied here, are identical in release: a room with a source of ignition, a combustible mixture + combustive saturated with fuel and which thus misses the combustive one. The opening of one opening brings missing oxygen, makes go down again the combustible mixture + combustive to the ideal proportions and it is the explosion.

Beyond this similarity of release, the phenomena prove to be different: purely explosive in one case, near to a resumption of fire in the other. But these differences surely do not represent the two only possible cases: all the mixtures are conceivable, of unimportant with most dangerous.

Few calculations extrapolating dimensions of this mini-simulator on dimensions "with human size" show that it is necessary to be proof of the greatest prudence in the access of the buildings, whatever are dimensions, the sites and the contents.
In the same way, it proves that the observation of the smoke is a significant element in the analysis and the tactical choice. The "reading of fire" is undoubtedly a requirement obliged in the training. Understand and observe, for better firefighting.



The author

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