# THE VALIDATION OF THE EXPLOSIVE FUMES DYNAMICS IN ROOMS

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#### Abstract:

Last year the discovery of the explosive fumes dynamics in rooms was published. The fumes dynamics of TNT had been observed up to now only by numerical simulations with the software AUTODYN<sup>®</sup>6.1z. To validate the fumes dynamics within the first 10 ms after the detonation, a test room was equipped in the urban module in Meppen with different measuring sensors. For the first time high speed heat flux sensors were used in the test room parallel to numerous pressure- and temperature sensors resulting from cooperation with the German-French Research Institute Saint-Louis (ISL). The position of the hot fumes cloud could be determined exactly by the installation of the measuring sensors close to each other and by the triggering of the measuring signals at the same time. Optical tests of validation took place in addition also in the Fraunhofer Ernst-Mach-Institute (EMI) in the laboratory scale (1:10). The measurements and optical pictures confirm in principle the existence of the fumes dynamics of TNT in rooms. There for, the simulation results of the software AUTODYN<sup>®</sup> 6.1z are also validated in principle.

Keywords: Simulation, AUTODYN, TNT, Fume, Dynamic, Room, Validation, Test

#### **1. INTRODUCTION**

The objective of the investigations was to validate the TNT fumes dynamics in closed rooms. The fumes dynamics was discovered in basic numerical simulations with the software AUTODYN<sup>®</sup> 6.1z for the project **SIBEX** (Shock Insensitive Blast Enhanced EX plosives). For these validation tests in the new urban module in Meppen the measuring points had been fixed by other principle simulations for the necessary pressure- and temperature sensors, because just pressure measurements are not suitable for a validation of the fumes dynamics <sup>[1, 2, 3]</sup>. Now after this specification in a well-chosen closed test room in the urban module numerous pressure, temperature- and novel heat flux sensors were built in. Three validation tests with 1kg-TNT-charges were carried out in one corner of the test room. The evaluation of the measuring results was limited to the first approx. 15 ms after the detonation to prove the fumes dynamics in closed rooms.

### 2. DESCRIPTION OF THE EXPERIMENT SET-UP

Within the scope of the definition of the measuring points for the pressure-, temperature- and heat flux sensors an almost closed test room was selected in the urban module <sup>[1]</sup>. This test room has only one passageway to the corridor and was provided with a pressure resistant steel door. The construction of this steel door occurred on the basis of the pressure values ascertained by numerical simulation. The function of this steel door was to hold the TNT fumes possibly approx. another 15 ms after the detonation in the room. In addition, all gaps of the test room were filled with assembly foam, so that the test room was very "fumes-tight" during the test. In the **Fig. 1** the modelled test room including the door with the planned measuring points in the side wall and front wall is shown as well as the ceiling. **Fig 2** shows a photo of the experiment set-up in the test room. You see clearly the yellow racks to which the pressure-, temperature- and heat flux sensors were fixed.



**Fig. 1.** Model of test room with measuring points intended to be in the walls as well as ceiling<sup>[1]</sup>.



**Figure 2.** Construction of the pressure-, temperature- and heat flux sensors in the test room of the urban module in Meppen to the validation of the TNT fumes dynamics <sup>[6]</sup>.

The photo in <u>Fig. 3</u> shows striking for the front wall and ceiling in the side wall of the urban module built-in pressure- and temperature sensors from the WTD 91 and the heat flux sensors from the ISL. Because of the restricted number of temperature- and heat flux sensors not all intended measuring points could be equipped completely with measuring sensors.



**Figure 3.** Measuring points 2, 10 - 12 and 5 in the side wall, partially equipped with pressureand temperature sensors of the WTD 91 and heat flux sensors of the ISL <sup>[6]</sup>.

In <u>Fig. 4</u> are clearly to recognise the measuring points 16 - 18 on three racks of different height in the test room. These measuring points all were equipped completely with measuring sensors. Every rack was fixed on the ground with four screws and also stood firm to the 1 kg TNT charges. The 1 kg TNT spheres which were used for the tests had been produced in the WTD 91. As a booster charge 50 g PETN was used and for the ignition a detonator DM 42, 1 ampere, see <u>Fig. 5</u>. This TNT sphere was fixed in one room corner (approx. 1 m from both walls and 1 m above ground). After all measuring sensors were built-in in the test room / on the racks, their installation place / position was exactly measured.



**<u>Figure 4.</u>** Fully equipped measuring points 16 - 18 on the differently high racks in the room diagonal <sup>[6]</sup>.



**Figure 5.** In the WTD 91 produced 1-kg TNT sphere with 50 g of PETN booster charge and detonator DM 42, 1 ampere<sup>[6]</sup>.

For the first time during the explosive tests the novel heat flux sensors which have been produced by the shock wave laboratory of the RWTH Aachen University (RWTH Aachen) <u>Fig. 6</u> were used.



**Figure 6**: View of heat flux sensors (fast coaxial thermocouples) of RWTH Aachen<sup>[4]</sup>. With friendly approval of Mr. Olivier.

The heat flux sensors which were used were fast measuring coaxial thermocouples of the model KL, type E. An exact description of the construction of these thermocouples is found in Internet <sup>[4]</sup>. "By grinding the head of the probe a junction between the two different metals is achieved. The thin grinding burr represents the thermal active part which, due to its small mass, yields a fast response time of the probe in the order of a few <u>microseconds</u>. A temperature change at the thermocouple junction leads to a change of a thermo-electric voltage which can be measured directly. The temperature coefficient and the thermal properties of the thermocouple are determined by static and dynamic calibration. Considering short measuring times, the classic equations of the heat transfer into a semi-infinite slab can be used to determine the heat flux." Hence, before every test all heat flux sensors became short grind on the surface. As a measuring value the change of voltage was recorded from the heat flux sensors which were completely sufficient for the proof of the fumes dynamics. Also all other measuring sensors have been checked for the temperature- and pressure measurement as well as measuring lines to the record devices. After fixing the prepared TNT-sphere in the test room the steel door was closed and the test was carried out.

Although all measurements should begin with only one common trigger signal to be able to assign exactly time wise the measuring values later to each other, a common trigger occurred only with the pressure- and heat flux measurements. So in the following chapter only the pressure- and heat flux measurements can be assigned chronologically.

## **3. RESULTS**

From the three carried out tests, a total of 135 usable measuring value histories of 18 pressure-, 15 temperature- and 12 heat flux sensors are given. Only few sensors failed during the test or with the measurement. However, the measuring results of these sensors can be still evaluated up to the time of her failure. Only the most important usable measuring histories which serve unambiguously for the proof of the fumes dynamics are gathered here.

A heat flux is generated by shock waves as well as by hot fumes. This becomes clear from both **Figures 7 and 8**. While at the wall (Fig. 7) within the first 15 ms after the detonation only a heat flux is generated by the shock wave or shock wave reflexions, a heat flux is generated in the room inside (Fig. 8) by the shock wave <u>and</u> the immediately following hot fumes as well as shock wave reflexions. This heat flux behaviour only observed in the room could not be observed at the wall, i.e. hot TNT fumes have not reached the measuring points in the wall within 10 ms after the detonation. The distance between measuring points 6 and 16 to the TNT sphere was approx. 1 m.



**Figure 7.** Pressure- and heat flux histories at the wall (test 2, measuring point 6, detonation of 1 kg TNT sphere in the room corner)<sup>[6]</sup>.



**Figure 8.** Pressure- and heat flux histories inside the room (test 2, measuring point 16, detonation of 1 kg TNT sphere in the room corner)<sup>[6]</sup>.



**Figure 9.** Excitation temperature histories of the measuring point 6 and 16, test 2<sup>[6]</sup>.

This difference also becomes clear from the temperature measurement histories, in particular it is looked at measurements for a longer time. In **Fig. 9** the temperature measurement histories are compared in the measuring point 6 and 16 (like in Fig. 7 and 8) from test 2 over 50 ms. The difference by the temperature approx. 2,000 °C to approx. 1,500 °C is clearly recognised as well as the temporal duration of the temperature maximum of approx. 2 ms to approx. 10 ms.

## 4. OTHER VALIDATION TESTS

The "model theory" according to Cranz for the easy shock wave propagation of classical explosives is gathered in the **Fig. 10**<sup>[5]</sup>. Therefore, the recording time t' in the model, is exactly less by the scale factor k than in the original recording time t. In a model with the scale factor k = 1 : 10 the real-time t = 10 ms corresponds with t' = 1 ms in the model. The fumes dynamics in closed rooms was validated optically by the model experiments (1:10) done by the Ernst-Mach-Institute which illustrated the test room of the urban module in Meppen<sup>[6]</sup>. The fundamental experiment set-up in the EMI is shown in **Fig. 11**. Three video recordings (presentation only in Pardubice) recorded by EMI show clearly that after the detonation of the explosive in the corner of the scaled test room the luminous explosive fumes are pressed in the room middle within one millisecond by the shock wave reflexion and swing a little bit back to move again in the middle afterwards. Then there ends the luminous appearance of the fumes (On account to the video recordings the whole duration of the own lights illumination of the fumes cloud with approx. 4 ms could be determined).

In principle the AUTODYN simulation results are validated with the EMI tests, as well as the measurements are confirmed in the urban module.

# Theory of full scale and small scale Tests

# Model of Cranz

model (*I*<sup>r</sup>) and original (*I*) during shock waves investigation (without pressure- and fumes-reflections)

Length:	l" = k * l
Area:	$A^{t} = I^{t_{2}} = k^{2} * I^{2} = k^{2} * A$
Volume:	$V' = I'^3 = k^3 * I^3 = k^3 * V$
Mass:	$m' = \rho' * l'^3 = \rho' * k^3 * l^3 = \rho' / \rho * k^3 * m$
Time:	t' = k * t
Velocity:	v' = l' / t' = (k * l) / (k * t) = v
Acceleration:	$a' = v' / t' = v / (k^* t) = a / k$
Force:	$F' = m' * a' = (\rho' / \rho * k^3 * m) * (a / k) = \rho' / \rho * k^2 * F$
Tension:	$\sigma' = F' / A' = (\rho' / \rho * k^2 * F) / (k^2 * A) = \rho' / \rho * \sigma$
Aktivity:	$W' = F' * I' = (\rho' / \rho * k^2 * F) * (k * I) = \rho' / \rho * k^3 * W$
Energy:	$E' = \frac{1}{2} * m' * v'^{2} = \frac{1}{2} * (\rho' / \rho * k^{3} * m) * v^{2} = \rho' / \rho * k^{3} * E$
Momentum:	$I' = m' * v' = (\rho' / \rho * k^3 * m) * v = \rho' / \rho * k^3 * I$

If air and explosive in model and original indentical, than  $\rho' / \rho = 1!$ 

**Figure 10.** "Model theory" according to Cranz for blast investigations<sup>[5]</sup>.

# **Experiment Set-up**



**Figure 11.** Scaled experiment set-up (1:10) from EMI<sup>[6]</sup>. With friendly approval of EMI.

## **5. CONCLUSION**

A clear difference could be ascertained by the simultaneous heat flux- and pressure measurements between the measuring results at the walls and in the test room inside within the first 15 ms after the detonation. A heat flux is generated by shock waves as well as by hot fumes. While at the wall within the first 15 ms after the detonation only a heat flux is generated by the shock wave or shock wave reflexions, a heat flux is generated in the room inside by the shock wave and the immediately following hot fumes as well as shock wave reflexions. This heat flux behaviour only observed in the room could not be observed at the wall, i.e. hot TNT fumes have not reached the measuring points at the wall within 10 ms after the detonation. On account of these clear differences in the measuring results the fumes dynamics is validated. A confirmation of both statements is given therefore to the fumes do not touch the wall and that secondly at that time the fumes are near the middle of the room. In the meantime, the Ernst-Mach-Institute in Freiburg also was able to validate optically in the model graduation the fumes dynamics in closed rooms.

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