

# Testing and construction of experimental stands for hydrogen explosions

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**Abstract.** The paper presents the design, construction, and testing stages of experimental stands developed for investigating hydrogen explosions. The specific technical requirements for such tests are discussed, including safety parameters, pressure control, and the structural features of the test chambers. The study details the constructive solutions implemented to ensure structural integrity during controlled explosions, the methods employed for monitoring critical parameters, as well as the integration of pressure measurement systems and Schlieren imaging techniques for capturing flame front dynamics. A key aspect of the study is the correlation between experimental tests and numerical simulations conducted on geometrically similar setups in virtual environments using Computational Fluid Dynamics platforms. This integrated approach enables the validation of theoretical models and the refinement of simulation parameters based on experimental data, contributing to an enhanced understanding of hydrogen explosion phenomena and supporting the optimization of experimental stand design. The paper concludes by summarizing the performance of the tested stands and their relevance in relation to experimental objectives and simulation results. In the design of the experimental stands, particular consideration was given to both the rectilinear propagation of hydrogen-air explosions and the change in trajectory of the explosive process at 90-degree angles.

## 1 Introduction

Hydrogen is increasingly being considered as a viable alternative to conventional energy sources, being an energy vector with zero emissions at the point of use. However, its widespread use is limited by the risks associated with its physicochemical properties, such as low molecular weight, high diffusivity, extensive flammability and high burning rate [1,2]. In particular, the explosion risk in air-hydrogen mixtures requires a detailed analysis of the mechanisms of flame initiation and propagation, as well as the development of technical solutions to prevent and mitigate explosive effects.

For a thorough understanding of the phenomenology of hydrogen explosions, experimental studies carried out under controlled conditions are essential. The construction of experimental stands dedicated to this type of research requires compliance with strict safety and precision requirements [3,4]. The stands must ensure structural integrity under

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explosion conditions, allow control of test parameters (pressure, temperature, mixture composition) and be equipped with high-performance monitoring systems. In addition, the geometry of the stands plays a significant role in the propagation of shock waves and the flame front, requiring the analysis of both rectilinear propagation and sudden deviations of the trajectory of the explosive process (for example, at angles of  $90^\circ$ ).

In order to carry out physical experiments (explosions of air-hydrogen mixtures) under safe conditions, while also considering the requirements regarding the accuracy of the recordings of the explosion process parameters and those imposed by the recording techniques, as well as the use of experimental models in complex scenarios, the following design criteria were developed:

- to facilitate the application of Schlieren methodologies for the continuous recording of the rapid combustion phenomenon. For this, the experimental model must be transparent on the vertical recording axis and dimensionally fit within the circumference of the parabolic mirrors (with a diameter of 412.8 mm) required by these techniques [5,6];

- to allow the configuration of the model in interconnected spaces by placing obstacles with membraned holes;

- to allow the use of membrane obstacles with openings of different shapes (circular, square, rectangular, elliptical, etc.) and with membranes of different thicknesses;

- to ensure a higher degree of precision in measuring local/global speeds and accelerations;

- to ensure the possibility of recording pressure values in each interconnected spaces;

- to allow the analysis of pressure variations when changing the direction of propagation of gaseous explosions and when penetrating obstacles with different resistance;

- to allow the analysis of chain gas explosions;

- allow the location of the initiation source to be changed;

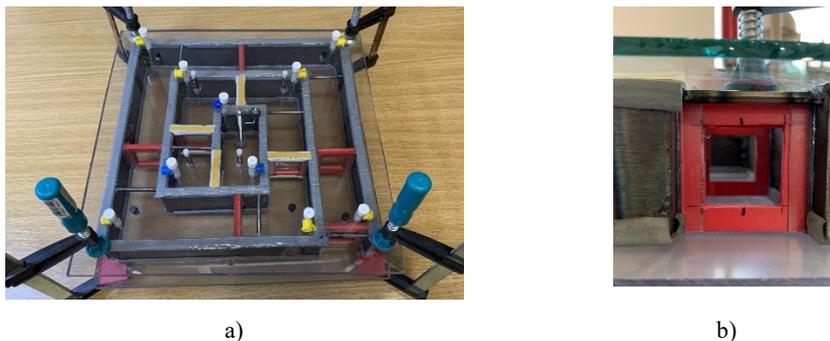
- to be resistant to the overpressure values generated by the explosion.

Given that in the case of explosions with a change in the direction of propagation of the pressure wave a more complex experimental model is used, it is considered that the experimental model that will be used for the analysis of explosions with linear propagation can be realized by fulfilling the same constructive conditions (in terms of the materials used). This is motivated by the fact that the overpressures generated by explosions of air-hydrogen mixtures, in the case of a change in the direction of propagation, are considered superior to those generated by explosions with linear propagation [7,8].

## 2 Experimental stand design

### 2.1 The first concept

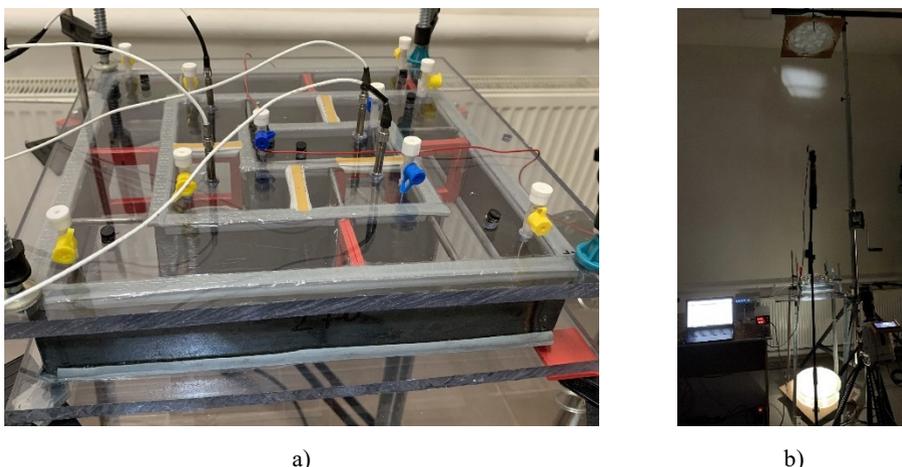
Considering the criteria presented in the previous chapter, the experimental prototype was conceptualized in the configuration of a rectangular spiral, constructed with metallic walls, to guarantee the material's resistance against overpressures exerted in the horizontal plane. The spiral shape offers the possibility of analysing the explosion process with a change in the propagation direction, on this path being arranged membrane obstacles, which divide the internal volume of the spiral into separate chambers (Figure 1).



**Fig. 1.** Experimental stand with metallic walls a) and the membrane shutters that separate the combustion chambers b).

In order to fulfil the requirement of transparency along the vertical axis, as mandated by Schlieren recording methodologies, the metallic spiral is enclosed at both the inferior and superior ends by two polycarbonate plates, a substance that guarantees both optical clarity and resistance against overpressure simultaneously. Consequently, high-velocity video recording is significantly enhanced by the transparency exhibited in the vertical plane of the experimental apparatus, facilitating the collection of data pertaining to fluid velocities during the explosive event and the analysis of the behaviour of the flame front, in addition to delineating critical phases throughout this phenomenon (initiation of the explosive environment, rupture of membranes).

The collection of explosion overpressure data is achieved by mounting pressure sensors in the holes of the upper polycarbonate plate. The recorded signals are transmitted, through an amplifier, to the computing unit for analysis. The ignition system consists of an electric spark generator with electrodes positioned inside the explosion cell, at the centre of the spiral. (Figure 2).



**Fig. 2.** Experimental stand with equipped with pressure sensors and initiation system a) and the integration of the stand into the Schlieren arrangement b).

In the same time with the construction of the experimental stand, a computer simulation was performed on a virtual geometry identical to the real one. Computational simulation was performed to determine the maximum overpressure acting on the walls of the stand.

Initial settings of the explosion in the fluid environment:

Cells set with explosive atmosphere: 1, 2, 3 and 4, starting with the cell in the centre of the spiral;

Hydrogen concentration in air: 20% vol H<sub>2</sub>;

Temperature: 20°C;

Pressure: 101325 Pa;

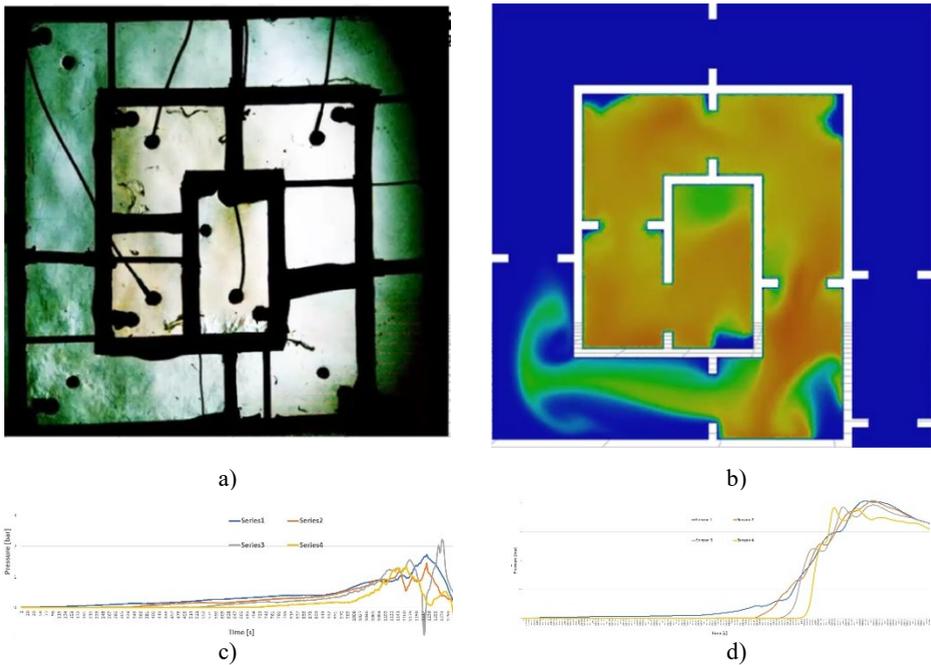
Initiation point: cell 1, in the centre of the spiral.

The computational simulation of the air-hydrogen mixture was carried out in two stages:

- the first stage focused on the explosion process and included only the fluid volume of the prototype. Pressure values were recorded on the surfaces of the boundary walls, along with the maximum overpressure within the cells filled with explosive atmosphere. The membranes between the cells were removed (resulting in open surfaces), so that the cells were delimited solely by the membrane support frames. The computational simulation was carried out in ANSYS Fluent;

- the second stage of the simulation consisted of taking the data obtained in the first stage, namely the pressure values on the wall surfaces and applying them to the surfaces of the solid bodies (the contact surfaces between fluids and solids). The simulation was performed in ANSYS Transient Structural.

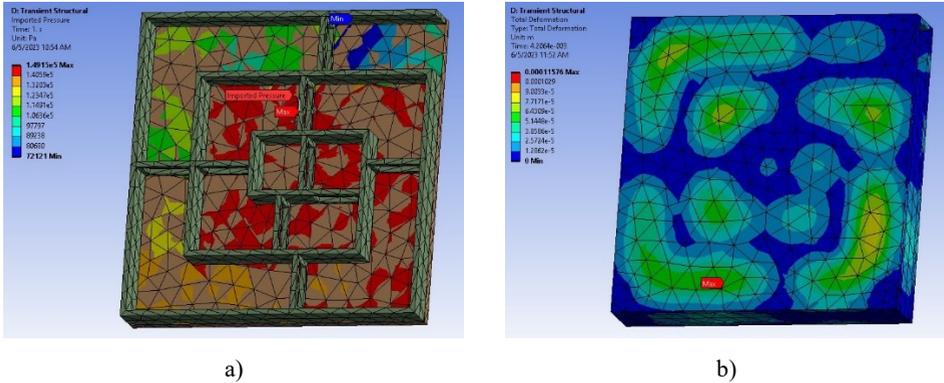
The comparative imaging results between the physical and virtual experiment showed a high degree of similarity in terms of flame front behaviour (Figure 3, a and b). Also, the maximum values of the explosion overpressures are very close, namely 2.18 bar recorded during the experiments and 2.03 bar obtained in the simulation (Figure 3, c and d).



**Fig. 3.** Physical experiment of hydrogen explosion visualized by the Schlieren effect a), flame front observed in computational simulation b), pressure variations in physical explosion c) and pressure variations in computational simulation (d).

Although the results of the computer simulation are similar to the real ones, during the explosive process a gas leak was observed from the chambers located in the centre of the spiral towards the marginal chambers, due to the loss of tightness due to the deformation of the transparent plates - upper and lower - of the stand under the action of the explosion

overpressures. This fact led to the realization of the second stage of the computer simulation, which consisted of taking the pressure fields recorded on the surfaces of the walls of the stand and applying them to the virtual geometry of the objects that delimit the fluid volume of the interconnected spaces. Thus, the deformation of the polycarbonate plates and the explanation of the pressure leaks between the chambers were obtained (Figure 4).

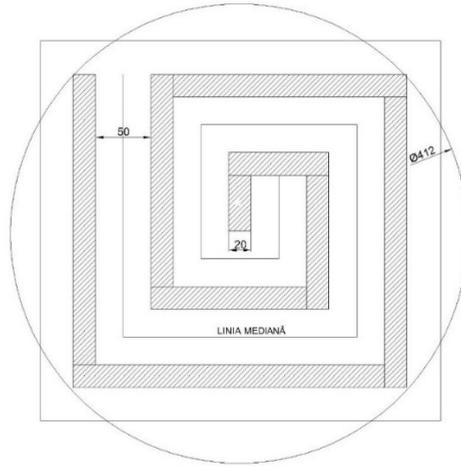


**Fig. 4.** The pressure field transferred from the first stage and applied to the solid walls of the stand a) Deformations of the polycarbonate top plate, indicating locations of gas leaks between the stand chamber volumes b).

It should be emphasized that the computational simulation of the dynamic effects is intended to approximate the overpressure values generated by the air–hydrogen explosion, without validation against geometric measurements of movements or displacements from physical experiments. Nevertheless, the obtained dataset offers the designer a useful reference for sizing the polycarbonate sheets and determining the assembly method of the experimental model.

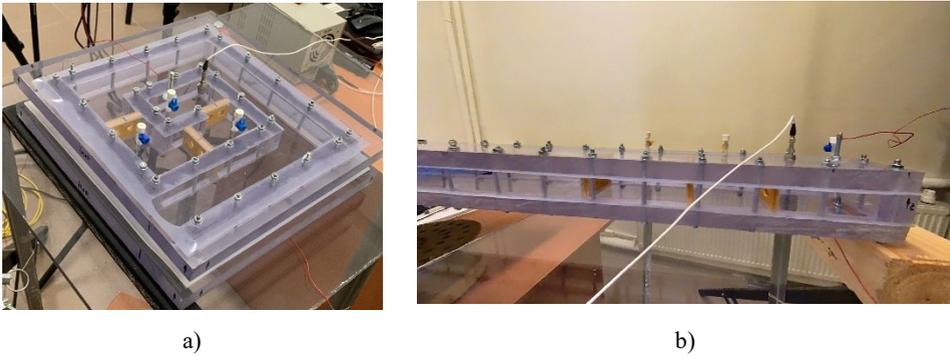
## 2.2 The second concept

The second tested construction was made entirely of polycarbonate sheet with a thickness of 20 mm. Thus, the thickness of the walls increased by decreasing the length of the median line of the rectangular spiral. However, the section of the spiral tunnel remained the same (50 x 30 mm). The shutters were modified compared to the first stand model, instead of the membrane rectangles, two holes with a diameter of 12 mm were arranged in each shutter. The stand was also equipped with 4 pressure sensors and an explosive mixture initiation system, the electrodes being placed in the central chamber (Figure 5).



**Fig. 5.** The second rectangular spiral stand

One of the objectives of future research on hydrogen explosions being to carry out a comparative study between the linear modes and the ones with a change in the propagation direction of the rapid combustion process, another rectilinear stand was constructed (Figure 6 b), with a length identical to the median line of the spiral stand (Figure 6 a).



**Fig. 6.** The second rectangular spiral stand a) and the linear stand b)

### 2.3 Testing the functionality of experimental models

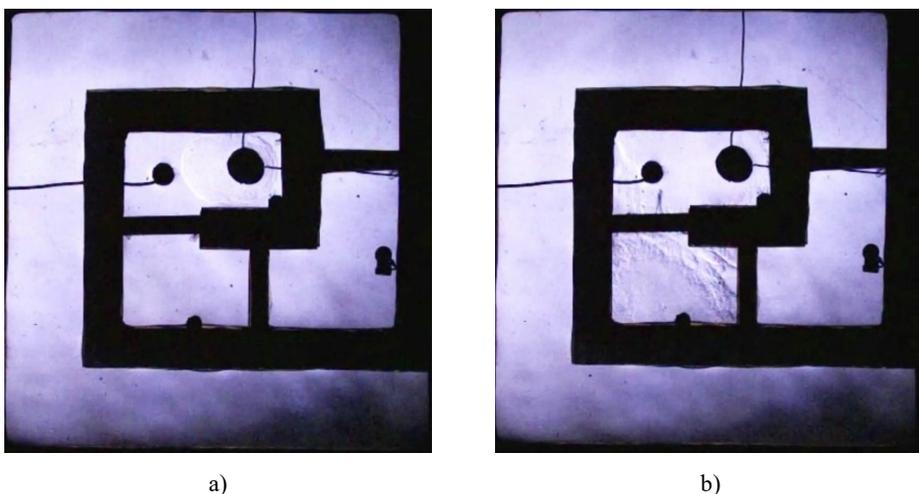
To test the functionality of the models, they were integrated into a recording system using Schlieren techniques, a system capable of highlighting the density gradients at the boundary between the flue gases and those in front of the flame front, in the development of the rapid combustion process.

In both cases (spiral and linear models) concentrations of 20%vol hydrogen in air were used to charge the 3 chambers separated by the previously described foiled orifice shutters. The first (initial) chamber of each model was equipped with a pressure sensor, with computer-assisted recording of the values. The volumes of the 3 chambers were 157.5 ml (chamber 1), 138 ml (chamber 2) and 193.5 ml (chamber 3), the rest of the explosion path being left open, in fresh air.

The video recordings were made using a high-speed Phantom camera, at a frequency of 30,000 fps.

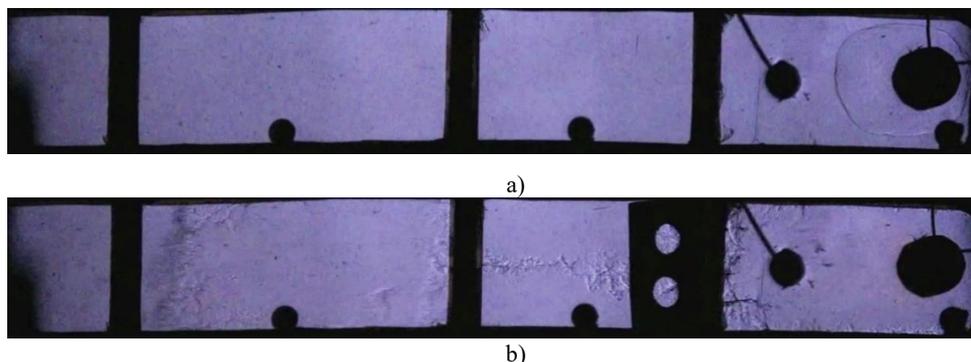
### 3 Results

The results, in the case of the spiral model, highlighted the initiation and development of the explosion of the air-hydrogen mixture and the propagation of the flame front through the 3 chambers (by breaking the shutter foils), the passage of the flame front into the space behind the shutters and its extinction with the consumption of the fuel support. During the experiments, no pressure losses were recorded between the interconnected chambers. Aspects of the explosion development at the experimental model level for the analysis of the explosion development of air-hydrogen mixtures, with the modification of the propagation direction, are revealed in Figure 7, a and b.



**Fig. 7.** Aspects of explosion development on rectangular spiral stand

In the case of the linear model, the process proceeded relatively similarly to the first case, with the difference that the first shutter was more dynamically affected than in the spiral model. During this experiment the flame front travelled through all 3 chambers, breaking the shutter foils and extinguishing when the fuel gas ran out (Figure 8, a and b).



**Fig. 8.** Aspects of explosion development on linear stand

## 4 Conclusions

Following the physical experiments of air-hydrogen explosions on the two models – linear and spiral – a good decision was found in the selection of construction materials and the way of assembling the elements, the experiments being carried out in perfect safety. No cracks/fractures/displacements were detected in the resistance structure of the models. The displacement of the shutters are predicted dynamic effects, normally generated by explosion overpressures. Thus, the experiments carried out prove the functionality of the two models both in terms of recording explosion pressures, as well as visualizing and recording the behaviour of the flame front and operational safety.

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