SIMULATION OF EXPLOSIONS IN FLOWVISION CFD SOFTWARE

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In the present paper the simulation of the explosion of condensed explosives in the air. The method used simulation by specifying the scope of compressed gas as the point source of the explosion. Describes the behavior of the blast wave on the middle and far distances from the source of the explosion, in which a pressure profile does not depend on the geometry of the source. The paper proposed to develop a method scope of the compressed gas provides the account properties of the products of the explosion for any explosive composition. Numerical investigation of the explosion of an explosive charge in the open countryside, in the presence of walls and rigidly fixed in the model of the urban environment. Shown good agreement with the experimental results and the peak pulse pressure both direct and reflected waves in each of the above cases.

Introduction

Simulation of blast wave in the air is of interest in assessing the effects of exposure to explosions and predestination scale destruction. The purpose of this simulation is to determine the dynamic load on the infrastructure - buildings and structures.

Formulation of the problem

We consider the propagation of the blast wave simulation of the explosion in an open space from a point source (explosion of condensed explosives). The aim of the work is to determine the adequacy of the proposed method of simulation explosion when compared with the experimental data, as well as the development of the proposed method by taking into account the properties of the detonation products.

To carry out simulation blast of C4 plastic explosives in an open space [2]. On the one hand from the epicenter is rigidly fixed wall, on which there is a reflection of the shock wave (see. Figure 1).

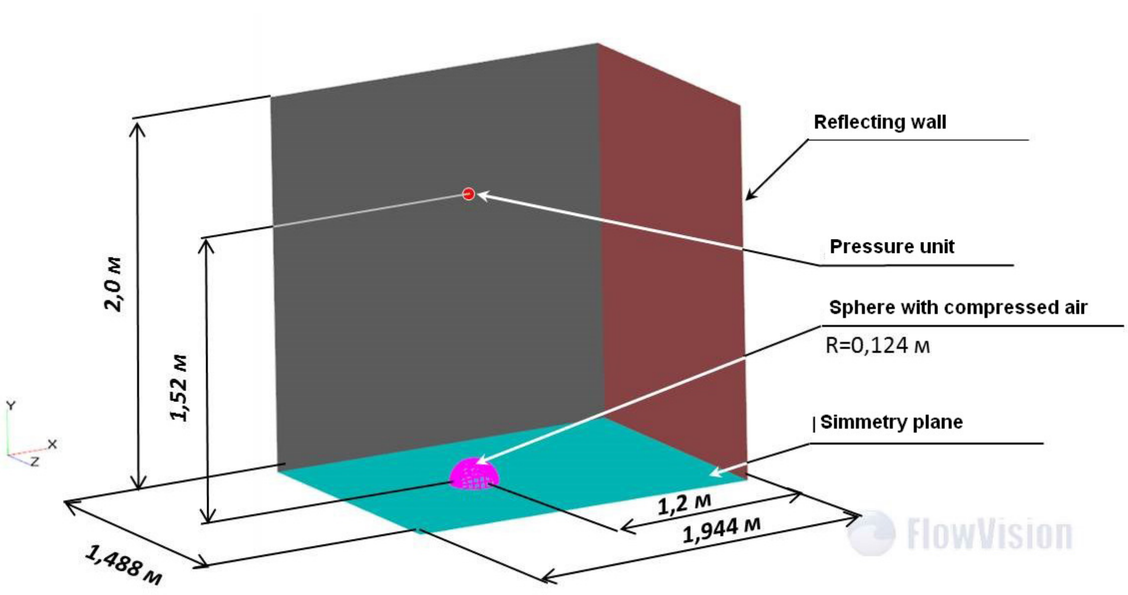

Figure 1 - Statement of the Problem

Comparison with experiment was conducted on the time dependence of the pressure in said sensor.

Testing techniques carried out on a series of calculations to debug the model two-dimensional formulation. The objectives of calibration calculations:

- Define the size of the settlement area;
- The impact of the type of the boundary conditions at the outlet of the computational domain (SU opposite reflective wall);
- Determination of the necessary steps to calculate the time integration and determination of the settlement scheme;
- Find the optimal grid (convergence on the grid);
- The impact of the initial conditions in the area and the impact properties of the products of explosive transformation.

The three-dimensional formulation also considered the impact of the computational grid, and was compared with experimental data, based on the analysis of the data presented recommendations for the use of this method.

Description of the method of modeling the explosion by a sphere of compressed gas (balloon method)

In solving this problem using a well-known and tested in many works [1, 3] a method of modeling job scope compressed gas as the source of the explosion. This method is the most versatile, provides sufficient accuracy for medium and long distances without a substantial increase in the cost of computing resources.

The explosion is modelled by specifying the initial conditions in the field of compressed air, the internal energy is equal to the energy of the explosion.

Assumptions:

- The size of the sphere is much smaller than the size of the study area of the blast wave propagation;
- To determine the pressure of compressed air used formula Brody:

$$p_{Brode} = \frac{E_{TNT}(\gamma - 1)}{V_{bal}} + p_0,$$

Where

E_{TNT}	energy charge J;
γ	1.4 - adiabatic index
V_{bal}	volume of a sphere with a compressed gas, m^3;
p_0	the initial pressure (atmospheric), Pa;

- Supposed adiabatic compression, gas - perfect;
- Properties of the gas inside the sphere correspond to the properties of air at given pressure and temperature;
- The explosion energy is expressed through TNT equivalent

$$E_{TNT} = M_{TNT} \cdot 4{,}52 \cdot 10^{6},$$

Where M_{TNT}

- TNT equivalent explosive, which is recommended to determine the magnitude of the momentum.
- The temperature of the compressed air is determined by the adiabatic equation:

$$T = T_0 \left(\frac{p_{Brode}}{p_0}\right)^{\frac{\gamma - 1}{\gamma}}$$

The initial and boundary conditions

As the reference values set pressure of 1 atmosphere and the temperature is 273 K. We are given two areas with the initial conditions (see. Figure 2):

- Terms of undisturbed air - in the whole computational domain

$P_{izb} = 0$;
T = 15 ° C.:

Compressed air - in the volume of the sphere. The initial conditions within the sphere of compressed gas depend on the volume specified by the scope. The pressure is determined by the equation Broad temperature - by adiabatic equation. Adiabatic index is assumed constant (γ = 1,4):

Pizb = 2.22 · 107 Pa;
T = 1073 ° C;
at V = 0,013 m3.

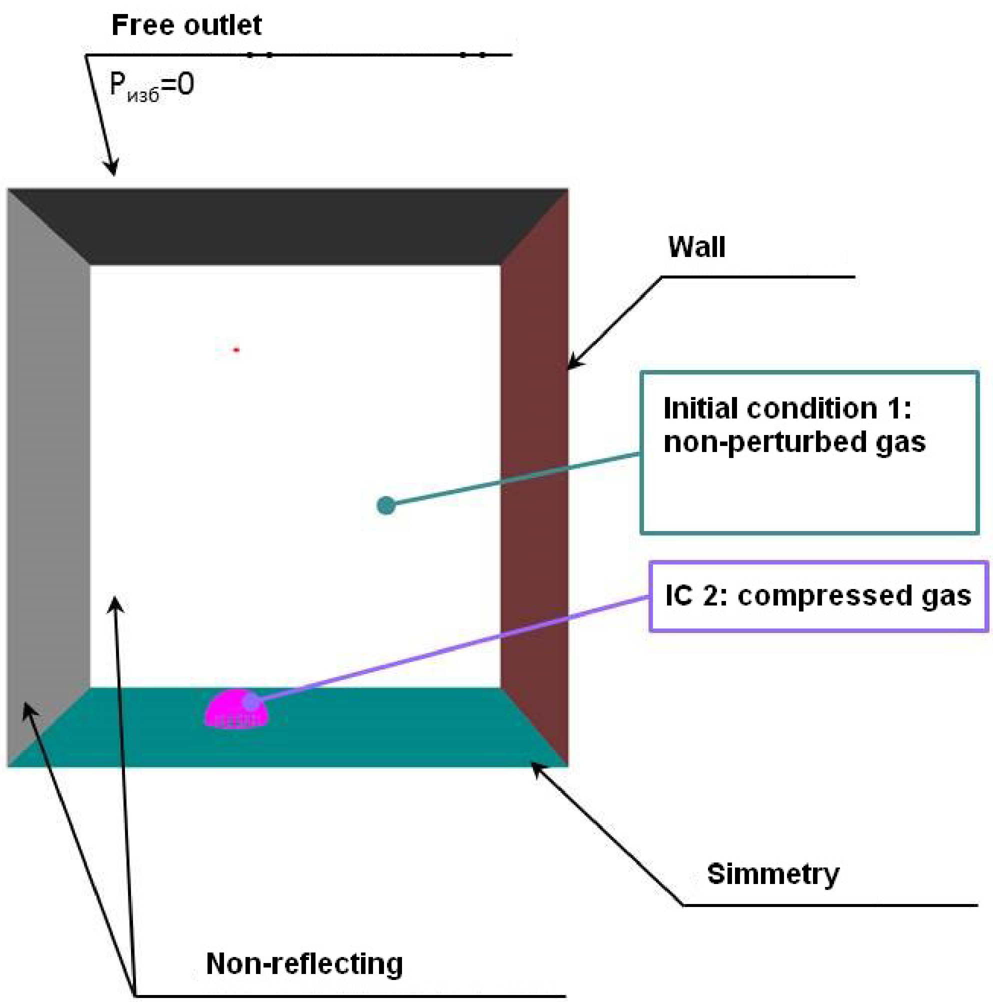

Figure 2 - The boundary and initial conditions

Mathematical model
In the simulation, the air is supposed to be ideal gas properties of the substances taken from the base PC FlowVision.

The simulated physical processes:

- Heat transfer to the air - convection and thermal conductivity;
- The movement of Newtonian fluid / gas.

The calculation parameters and additional options

- The calculation was made on the PC version FlowVision 3.09.03.
- The time step was set by the number of CFL = 1 and in the first 10 meters was limited by the size of 10-7 seconds.
- Integration scheme: Implicit "new" (2 nd order of accuracy).

Study of convergence of factors influencing

Testing methods of formulation of the problem in the PC FlowVision constructed so as to identify the main parameters affecting the change in the pressure line and the reflected wave, and define the boundaries of acceptable change for the accuracy of the numerical calculation.

1. The type of boundary conditions for the release of the blast wave

We investigated the type of boundary conditions set opposite reflective wall. The curve was taken as the reference time graph of pressure at the reference point in the computational domain obviously large with distance from the center of the explosion to the output twice larger than the distance from the explosion to the wall; ie parameter x = 2.4 m, which corresponds to the radius of the sphere 20 with compressed air (see. Figure 3). Type of State at the same time is set as "Free access" (red curve on the chart Figure 4).

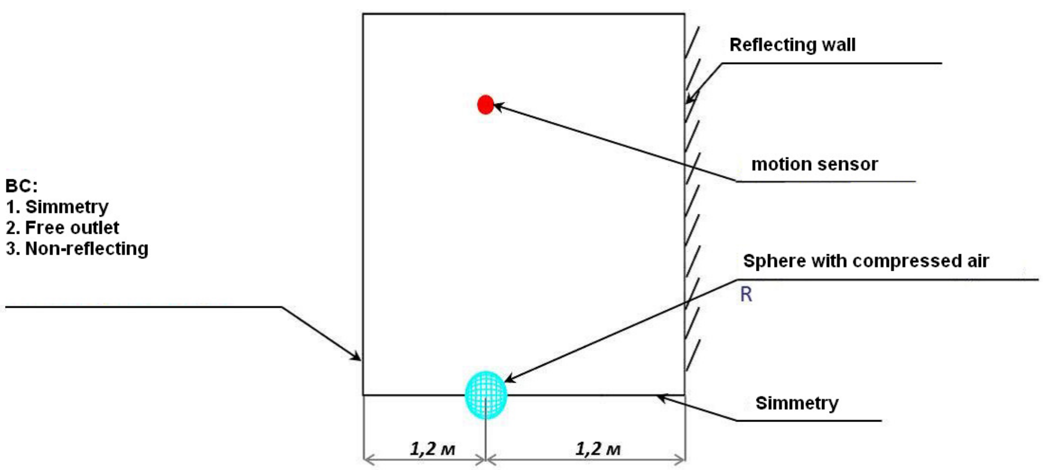

Figure 3 - Scheme of the study of boundary conditions

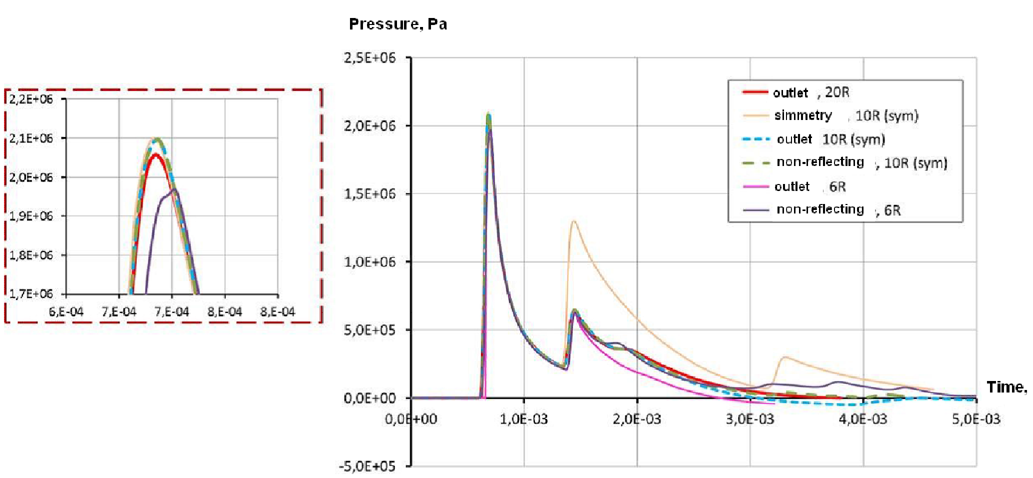

Figure 4 - Comparison of boundary conditions

As can be seen from Figure 4, the greatest impact on the type of State has the amplitude of the second pressure jump. And "Exit" and "Non-Reflective" GU showed good agreement with the reference curve. Installation PG type "Symmetry" reflection of the detonation wave occurs, and the peak of the second jump increases significantly (about 2 times). Therefore, the "symmetry" to set properly if we are interested in the behavior of the pressure not only directly, but also in the reflected wave from the obstacle.

2. The configuration of the computational domain

We investigated the distance of the boundary conditions set by the reflecting wall opposite from the explosion center (dimension x in Fig. 5) to determine the smallest size of the computational domain is sufficient that substantially reduce the need for resources in 3D-formulation. The criterion of adequacy - the constant pressure profile in the control point.

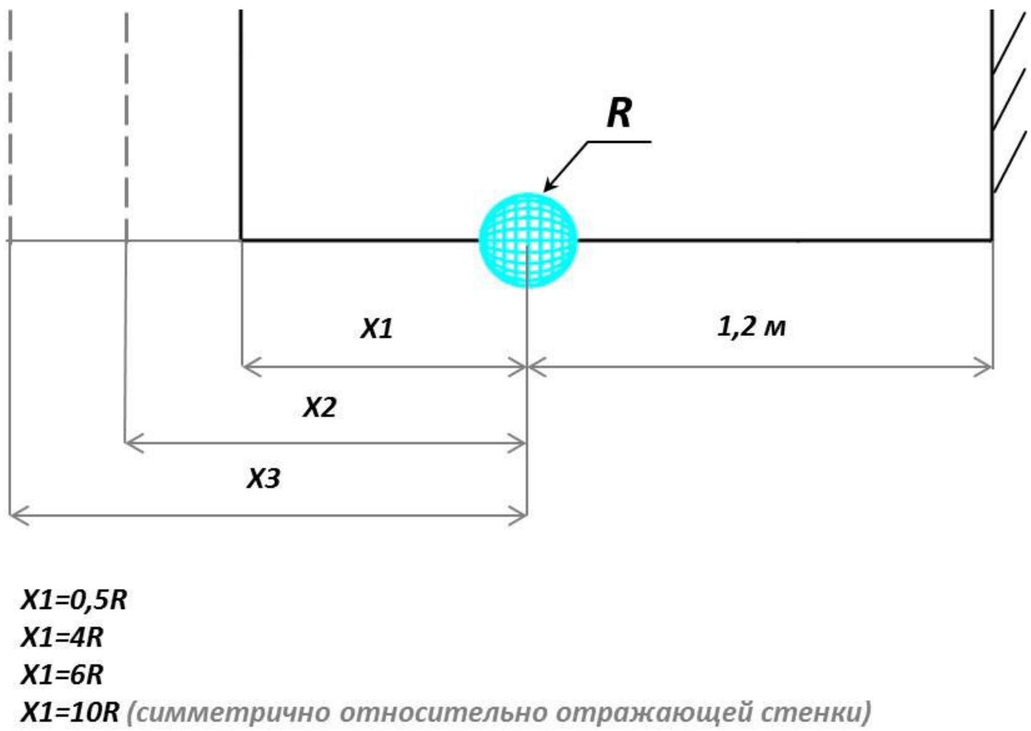

Figure 5 - Study of the computational domain configuration

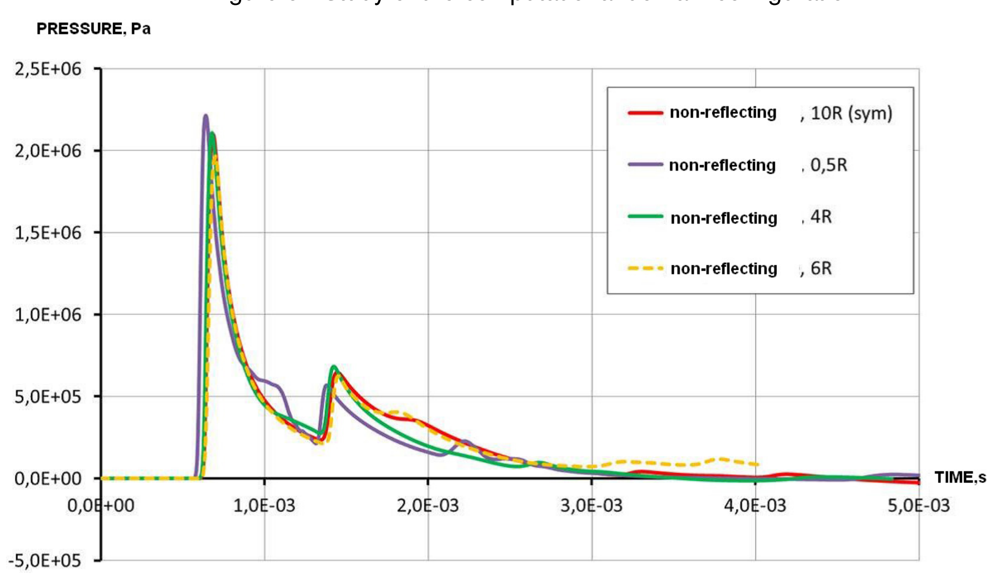

Figure 6 - Study of the configuration of the computational domain

It should be noted that the choice of the computational domain - a separate study, which is carried out when debugging a numerical experiment, especially in problems with the spread of the blast wave. It is worth considering the characteristic time for research and make sure that at this time do not form pressure peaks in the reflection wave from the State of interest to researchers in points (pressure sensors, wall construction, etc.). Guidelines for this work - the distance to the PG output waveform at least 6 radius of the sphere with the compressed gas.

3. Estimated Cell

The requirements for computational grid for the problems with the passage of the blast wave can be summarized as follows: the grid must, firstly, allow gradients values at the boundary with the area of the initial overpressure - for boundary sphere with compressed air. Second, the gradient magnitudes sufficient to permit the passage of the wave through the control point and near obstacles (in this task - reflecting wall surface). Therefore, adaptation (grinding) the grid in the study of convergence is carried out:

- Inside and on the Limits of the scope of the compressed air.
- The volume of computational domain to the objects of interest (pressure sensor)

The study determined the optimal computational grid (see. Fig. 7). The mesh should be set uniformly from the center of the explosion to the control point, a pressure sensor (size of the cell in the given situation corresponds to 6 mm), it does not require additional grinding mesh inside the sphere.

It is also allowed the use of adaptation to the decision to allow the pressure gradients. It is recommended to determine the grid so that the radius of the sphere accounted for 10 - 15 computational cells.

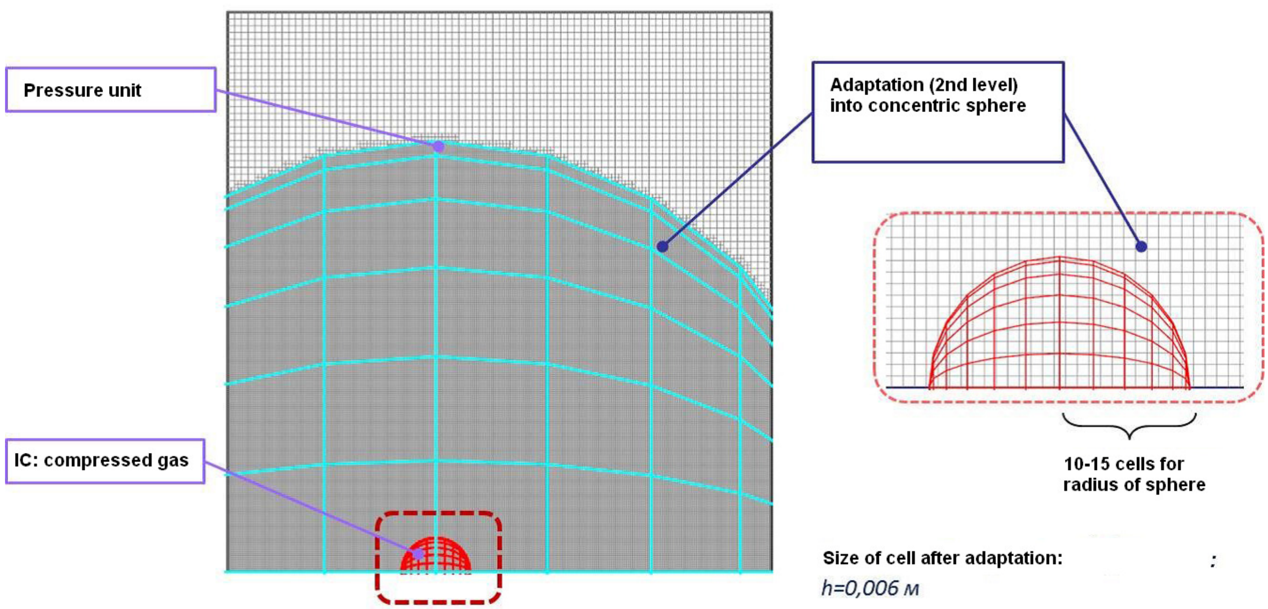

Figure 7 - Estimated Cell

4. Integration and design scheme

For optimal computational grid with the 2nd level of adaptation in the space of the calculations in steps CFL = 1; CFL = 2; CFL = 5 (a clear step at a time is τ = (1 ... 8) · 10-6 sec.) The results are shown in Figure 8. Increasing the time step to CFL = 2 leads to a shift of the 2nd jump (reflected) while maintaining the position of the 1st pressure jump and amplitude within ΔRmax = 3%. A larger increase in step affects both the arrival time of the waves (forward and reverse), and the amplitude of the reflected wave, so it is advisable to set pitch no more than CFL = 1 ... 2.

Use of an explicit solution scheme does not change the maximum pressure (ΔRmax≈7% in the 3D-formulation) or a significant reduction in the count rate (time difference ~ 5%).

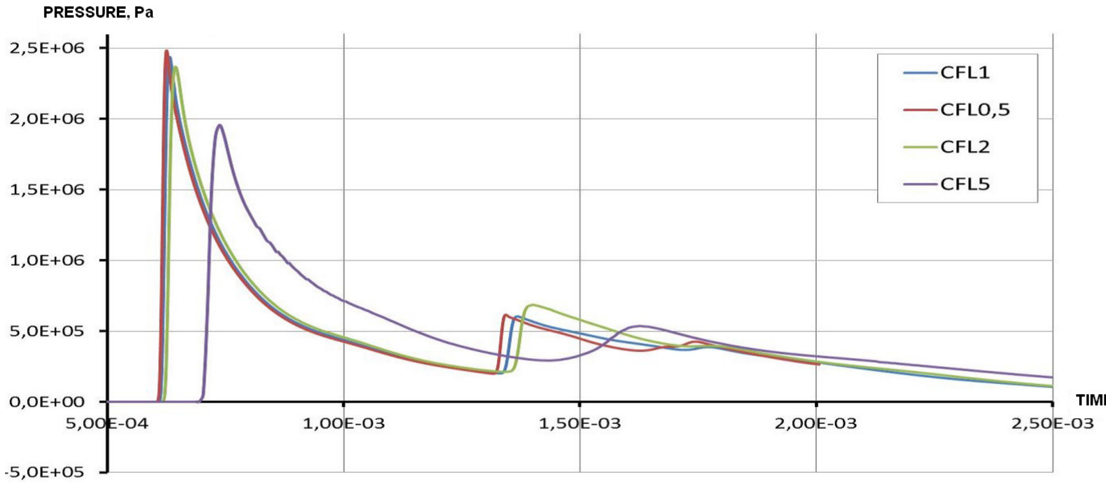

Figure 8 - Effect of the time step

5. Effect of initial conditions in a spherical region of compressed gas

A series of calculations in the two-dimensional formulation. Vary the volume of a sphere $Vbal$ compressed gas for which is uniquely determined by the pressure in the well at Broad equation:

$$p_{Brode} = \frac{E_{TNT}(\gamma - 1)}{V_{bal}} + p_0$$

It is shown that with increasing pressure significantly increases the peak pressure in the oncoming blast wave (Figure 9). Increased pressure in the incoming wave with the increase of pressure in the WELL - error method itself and defines the scope of its application, so you need to define the range specified by the pressure within the sphere of compressed gas.

Given the properties of the explosion products and the determination of the initial pressure

The objectives of this phase of work as part of a point explosion modeling techniques are to:

- To improve methods of compression volume ("ballon metod") by taking into account the specific properties of the products of the explosion of explosives:
- To determine the volume, pressure and temperature for the initial data without TNT, details of which may vary depending on the source or completely absent for the newly developed explosives.

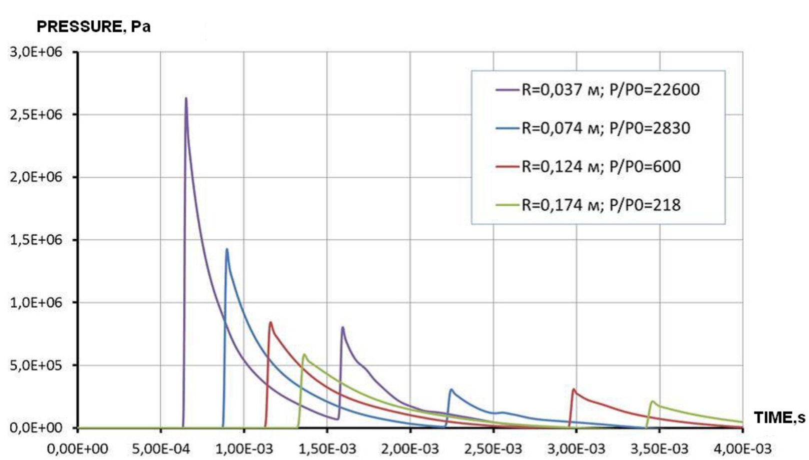

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Figure 9 - The effect of the initial pressure in

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The following assumptions:

- The release of internal energy occurs when the reactions of explosive transformation;
- The composition of the reaction products and their properties are determined by the conditions of thermodynamic and chemical equilibrium [7];
- The determination of the equilibrium properties and parameters taken into account the state of dissociation products at the explosion;
- It is assumed that after the detonation end product is a mixture of gases and are subject to the ideal gas law. Accuracy of using the equation of state for the heated gases at pressures of 100-200 bar. less than 2% [6];
- Extension to a predetermined pressure - adiabatic process.

The calculation is carried out in the following sequence:

a) Determination of the mass of the formulation and explosive properties of each component.
b) The calculation of the initial state to the detonation of explosives - the definition of the internal energy U0 explosive charge and the specific volume v0 (taking into account the mass content of the component).
c) Determination of specific volume mixture v1 for the received pressure and while maintaining the internal energy U0 BB for which the parameters are calculated equilibrium conditions and properties of reaction products of the explosion. The calculation is carried out in the TERRA program.
d) The specific heat and molar mass of the gas mixture is defined as the average for the enlargement process by a predetermined pressure (100-200 atm.) to atmospheric pressure.
e) Determine the radius of the sphere of the mass of the charge and the specific volume v1.

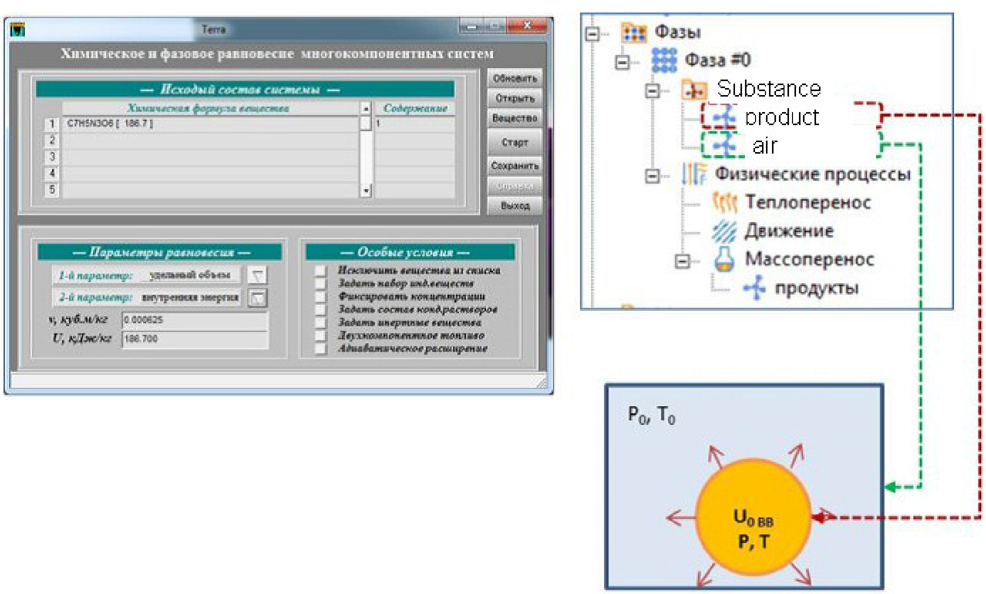


Figure 10 - Calculate the properties of the products of explosive transformation

The mathematical model of the process is added to the substance - the products of the explosion - and modelled by mixing with air by solving the equation for the concentration.

The account properties of the products of the explosion makes it possible not to apply for the calculation of TNT equivalent, of which data for the explosive can vary significantly or absent.

The calculation results

The curves of the pressure at different initial pressures in the area (within guidelines: 100-200 atm.) Without the properties of the explosion products, using equation Brody, and by calculating the theoretical composition of the explosion products as shown in Fig.11.

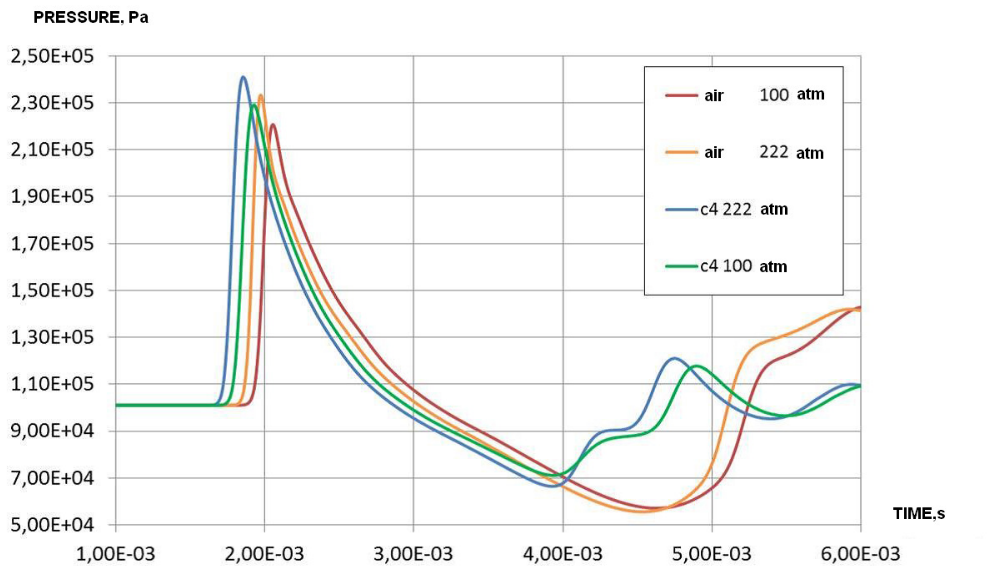


Figure 11 - Calculated pressure curves obtained by different methods and with different initial pressure in

Pressure curves obtained by setting properties of the explosion products did not differ significantly from the peak pressure of the incoming (primary) wave from the curves obtained using a reference method (compressed air); profile of the reflected waves at different times and peak pressures. Comparison with experimental data and data obtained by other computer codes, shows good agreement with experiment FlowVision calculations (see. Figure 12).

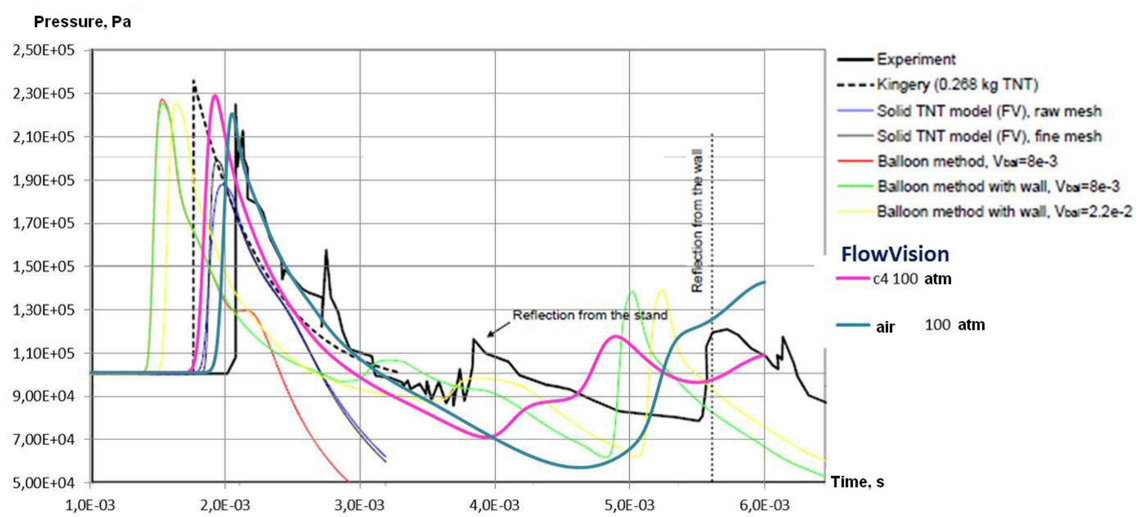


Figure 12 - Pressure in the control points obtained by different methods of modeling in comparison with experimental data

Recommendations for use of the method:

- When constructing the computational domain it is recommended to set the distance to the PG output waveform at least 6 radius of the sphere of compressed gas;

- The time step is necessary to set a maximum CFL = 1 ... 2;
- The computational grid must contain at least 10 cells on the radius of the sphere for the most accurate calculations;
- Explicit integration scheme increases the peak pressure in the incident blast wave (ΔRmax≈7%), the calculation time does not significantly affect (contrast ~ 5%);
- It is proposed to account explosion products solid and calculation of thermodynamic parameters at a given pressure, if there is data on the composition of the explosives;
- Pressure, defined in the initial conditions in the area of compressed gas is recommended to set the order of 100-200 atm.

Verification methodology

Verification of the method of calculation of explosions carried out on the following objectives: an explosion in an open space and an explosion in the model city street.

1. An explosion in an open space

To carry out simulation blast of C4 plastic explosives in an open space [2]. The problem is similar to that on which procedure was performed. The difference - another mass of plastic (454 gr.) And the absence of a reflective wall. Problem Statement - symmetric computational domain is 1/8 of the space (see. Figure 13). Static pressure sensor located above the center of the explosion at a distance of 1.52 m, and the comparison with experiment is carried out only for the direct wave. Shown good agreement with the experimental pressure profile amplitude and time parameters, the peak pressure is different from the experimental error in the range of 5% (see. Fig. 14).

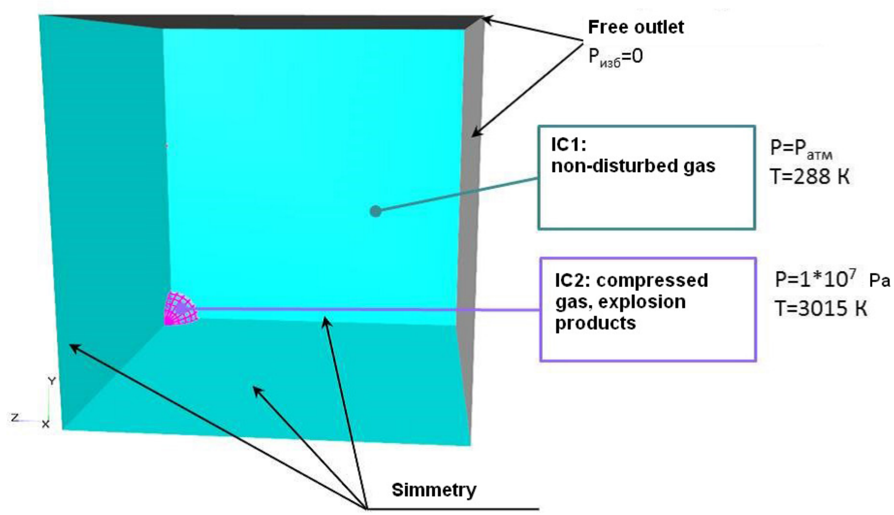
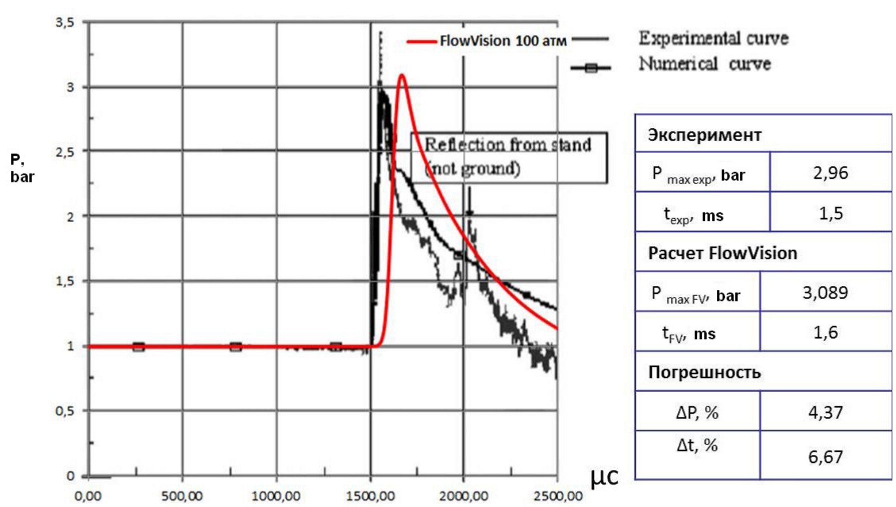


Figure 13 - An explosion in an open space: the formulation of the problem



Эксперимент	
$P_{max\ exp}$, bar	2,96
t_{exp}, ms	1,5
Расчет FlowVision	
$P_{max\ FV}$, bar	3,089
t_{FV}, ms	1,6
Погрешность	
ΔP, %	4,37
Δt, %	6,67

Figure 14 - An explosion in an open space: a comparison with experiment

2. explosion of TNT in a scale model of a city street

To carry out simulation of the explosion in the scale model of a city street. The charge of TNT weighing 8 grams. (1,0 lb) located in the center of the street. (see. Figure 15). Static pressure sensor located in the center of the faces of the building at the end of the street. Problem Statement - symmetric computational domain is 1/4 of the space.

The peculiarity of this task - the task well, in the hemisphere (the charge is on the surface).

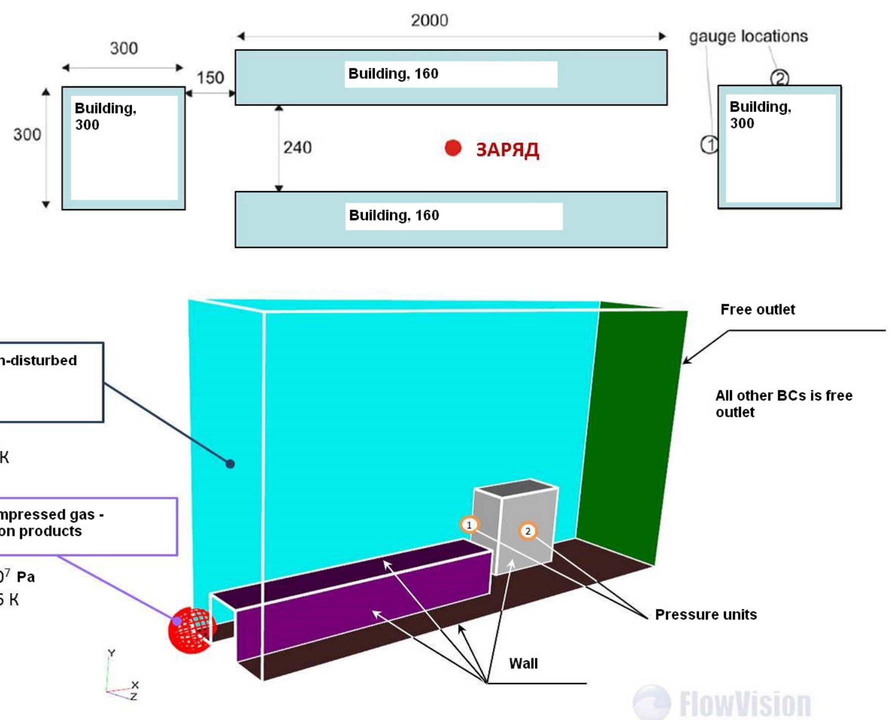


Figure 15 - An explosion in a model of a city street: formulation of the problem

Fig. 16 shows the successive moments of the pressure distribution on surfaces, clearly visible distortion of the spherical wave in the hallway between the two long buildings. Fig. 17 shows a comparison with experiment for each of the watchpoints. Obtain sufficient accuracy and qualitative description of the pressure profiles.

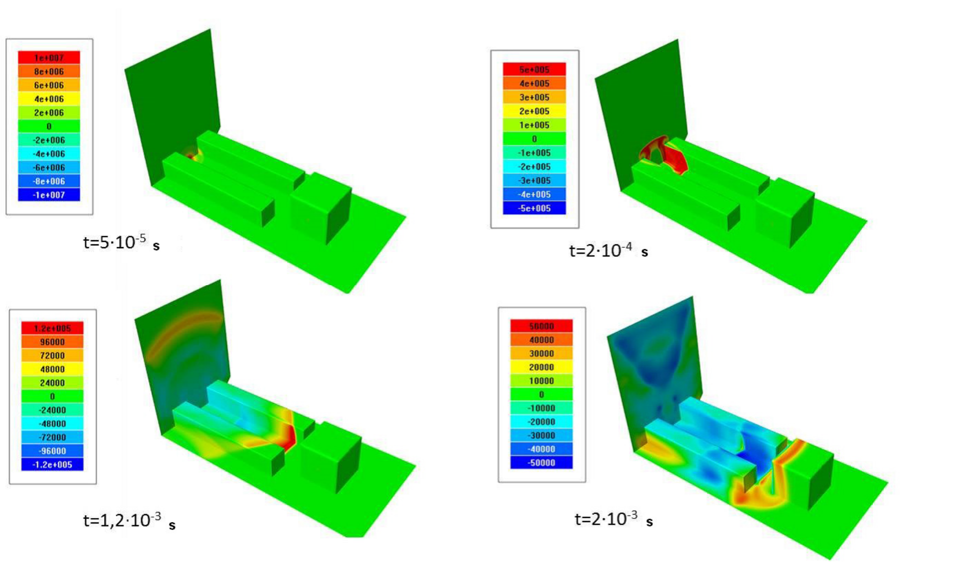
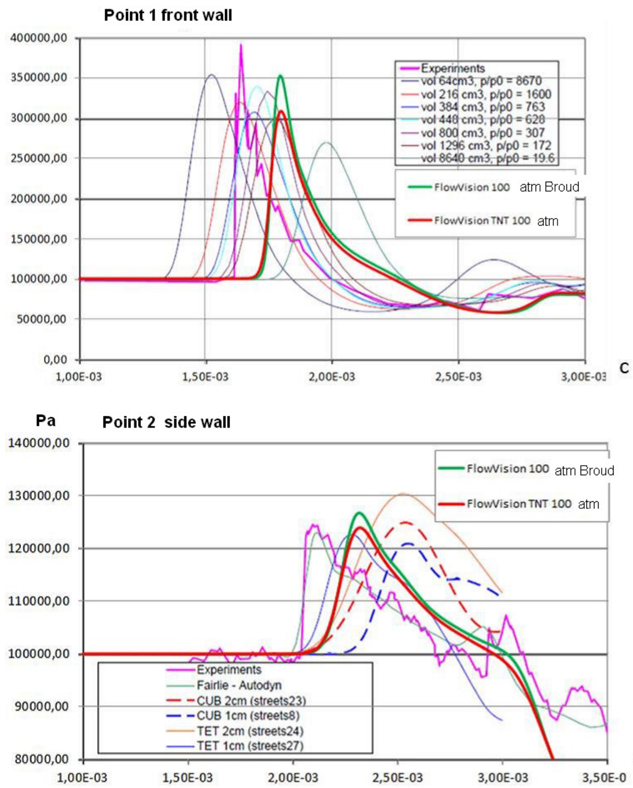


Figure 16 - An explosion in a model of a city street: the pressure distribution [On] on the surface of the object depending on the time



	Pint 1		Point 2	
Experiment				
P1 $_{max\ exp}$, Pa	3,930E+05		1,240E+05	
t1$_{exp}$, ms	1,62E-03		2,03E-03	
Simulation in FlowVision				
	Air	Trotyl	Air	Trotyl
P $_{max\ FV}$, bar	3,527E+05	3,086E+05	1,267E+05	1,239E+05
t$_{FV}$, ms	1,72E-03	1,70E-03	2,10E-03	2,08E-03
Error				
ΔP, %	10,26	21,47	2,21	0,05
Δt, %	6,17	4,94	3,45	2,46

Figure 17 - An explosion in a city street model: comparison with experiments and calculations in other codes

Conclusions

- The simulation of blast wave of compressed gas volume method using the equation Broad shown adequacy of the model used in the comparison with experiment.
- The method for calculating the properties of the detonation products and the initial conditions in the area of compressed gas.
- Recommendations on the use of this method of modeling of explosions
- The optimal parameters of the mathematical models and computational grid for this class of problems.
- The good qualitative agreement with the experimental pressure profile amplitude.
- The method of simulation of the explosion by a sphere of compressed gas for hemispherical OU without significantly reducing the accuracy of the calculation.

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