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19th DOE/NRC NUCLEAR AIR CLEANING CONFERENCE

SIMULATION OF EXPLOSIONS IN AIR CLEANING SYSTEMS AND COMPARISON OF THE RESULTS WITH COMPUTER CODE PREDICTIONS

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Abstract

Experimental testing and development of computer codes for predicting the effects of explosions in air cleaning systems are being done for the Department of Energy. The work is a combined effort by the Los Alamos National Laboratory and New Mexico State University (NMSU). Los Alamos has lead responsibility in the project and is developing the computer codes; NMSU is doing the experimental testing. Obtaining experimental data to verify the analytical work is the main goal of this effort. Of secondary importance are the experimental data showing the combined effects of explosions within air cleaning systems that contain all of the important air cleaning elements (blowers, dampers, filters, ductwork, and cells). This work will result in tools that safety analysts can use to study the effects of hypothetical explosions in nuclear facility air cleaning systems.

The experimental apparatus is a small version of a large experimental system that was installed at NMSU. The small system is used to obtain gas-dynamic data (temperatures and pressures) throughout the system (such as within the cells, along the ductwork, and before and after dampers and filters). Gas explosions are simulated in the experiments using a unique system of gas-filled balloons. The experiments will yield information on the degree of protection a system offers in attenuating explosive effects within air cleaning systems.

Analytical predictions were made using computer codes that predict gas-dynamic values such as flows, temperatures, and pressures throughout the system. The gas explosions were compared with the predicted results, and good agreement was found for most of the pressure measurements. Future experiments will involve small explosive charges using blasting caps or squibs. Future experiments also will couple material transport with the explosive gas dynamics.

Introduction

There is a potential for accidental explosions within nuclear facilities. (The recent reactor explosion at Chernobyl, Russia, is a case where a catastrophic explosion actually occurred.) In this country, safety analyses for nuclear facilities are required to evaluate the possibility and effects of accidental explosions thoroughly. Therefore, we want to develop computer codes that can be used to evaluate the effect of possible explosion-induced releases from a facility, perform scoping studies involving a multitude of explosion scenarios, and evaluate the effectiveness of various protective designs. To simulate these explosive effects accurately, we must be sure that the computer codes in use will perform as expected. This can be done by comparing the calculated simulations with small-scale experiments.

This paper describes computer codes being developed by the Los Alamos National Laboratory for the Department of Energy to simulate the effects of explosions within nuclear facilities. Particular emphasis is placed on explosive propagation in the plants' nuclear ventilation and air cleaning system. The experimental apparatus and results of tests using gas-filled (hydrogen/air) balloons to create gaseous detonations also are described. Finally, the test data are compared with computer code simulations.

Test Equipment Description

Figure 1 is a plan view of the experimental ventilation system located on the New Mexico State University (NMSU) Campus in Las Cruces. The ventilation system has two steel tanks simulating rooms. One tank is cylindrical and 2.74 m (9 ft) in diameter with a volume of 24.3 m^3 (859 ft^3). The second tank is essentially rectangular and 3.3 by 2.1 m (10.9 by 6.9 ft) on the sides with a volume of approximately 17 m^3 (600 ft^3). The tanks are connected by 0.305-m (1-ft)-diam ducts as shown in Fig. 1. Air is drawn through the system by a 28.4 m^3 (1000-ft^3/min) centrifugal blower attached to the exit duct of the cylindrical tank. Just upstream of the blower is a 30.5- by 30.5-cm (12- by 12-in.) high-efficiency particulate air (HEPA) filter and a 23.5- by 35.2-cm (9.25- by 13.875-in.) parallel-blade damper (fully open).

Shock waves are created in the system by exploding hydrogen/air-filled latex rubber balloons nominally 50.8 cm (20 in.) in diameter. The balloons are filled using a Matheson model 7372T gas proportional flowmeter through which the hydrogen and air flow simultaneously.

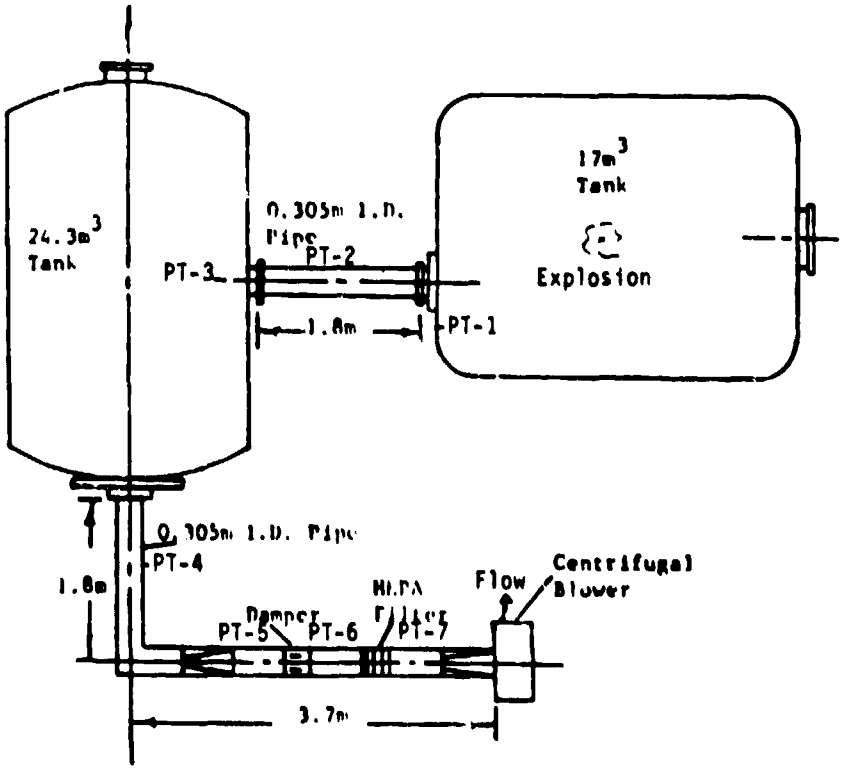

Figure 1. Plan view of the model ventilation system.

Figure 2. System for filling balloons with gas mixture.

The system for filling the balloons is shown in Fig. 2; Fig. 3 is a photograph of a filled balloon just before an explosion.

The shock wave created by the hydrogen/air explosion was measured by seven Kulite Model XT-190 miniature pressure transducers with a range of 0 kPa to 172 kPa (0 to 25 psia). All pressure measurements except those in the tanks were side-on measurements. The pressure transducer locations are shown by the symbol PT-X in Fig. 1. (X is a digit from 1 to 7.) The data from the pressure transducers were digitized and recorded by a high-speed CAMAC data acquisition system using a DEC PDP11/10 digital computer.

All seven pressure transducers were calibrated against a pressure standard before each experiment. The balloons were filled at a known flow rate for each gaseous component for a measured length of time. A small electrical impulse then caused the hydrogen-air mixture to explode, and the resulting shock wave automatically started the data acquisition system as it encountered a nearby trigger transducer.

Computer Code Description

Two computer codes have been developed at Los Alamos to calculate the gas dynamics associated with confined explosions: EVENT84 and NF85.[1,2] EVENT84 is an updated version of the EVENT computer code and includes an empirical explosion chamber model. Explosions involving TNT, H_2/O_2, acetylene, and red oil are calculated automatically as source terms for the explosion. NF85 is a fully three-dimensional explosion chamber model. It calculates the detailed driver gas dynamics for EVENT84, and its capabilities in simulating shock transmission tests were described earlier.[3]

The emphasis in this paper is modeling the overall system using the EVENT84 computer code. In addition, only gaseous explosions were simulated. Several methods other than NF85 were used to simulate the explosion.

- EVENT84 explosion chamber
- Approximate source-term method
- Pressure-time history

Computer Model for Test Simulation

Certain assumptions are made to model a system using EVENT84: perfect gas (air), compressible flow, momentum balance with friction and inertia, choking, linear and nonlinear filters, certain blower characteristics, and mass and energy addition to the gas phase. The model uses a lumped-parameter formulation; that is, no spatial distribution of parameters within network components is included. In addition, the analytical model must have the same arrangement of components, friction characteristics, capacitance, duct lengths, cross-sectional areas, boundary pressures, and driving forces as the experimental model.

The physical system is described first with a schematic consisting of a network of branches and nodes. Network theory defines system elements that exhibit flow resistance and inertia, or flow potential, as branches. The ventilation system components modeled as branches include dampers, ducts, valves, filters, and blowers. The connection points of branches are network system elements called nodes and always have a finite volume. Nodes include specific network components that have a finite volume such as rooms, gloveboxes, and plenums, or the node may contain only the volume of connecting branches. System boundaries, where the volume is practically infinite, also are specified as nodes.

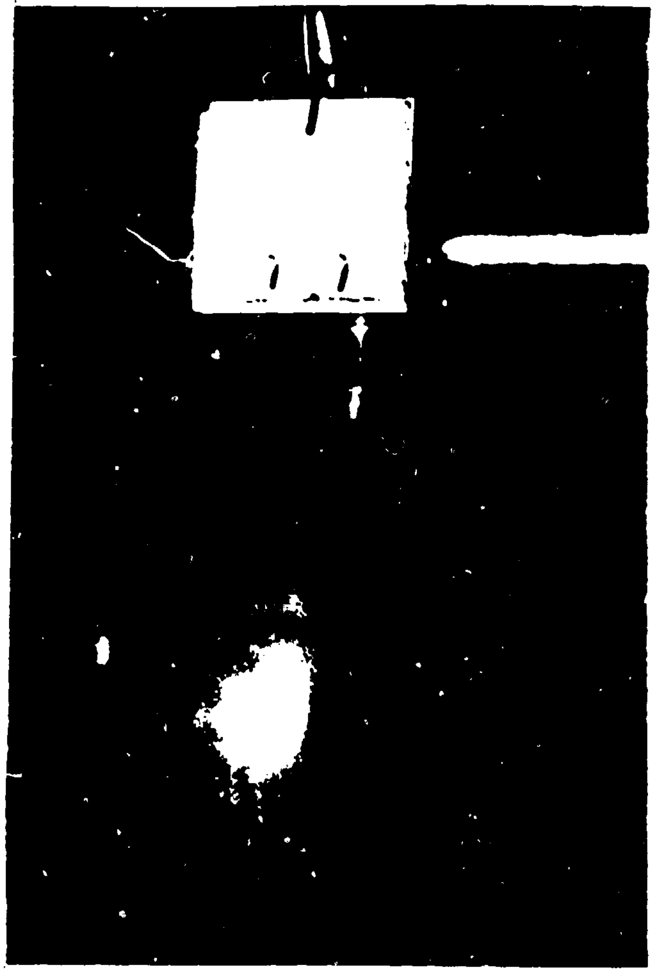

Figure 3. A gas-filled balloon just before an explosion.

The energy conservation equations are applied to internal (capacitance) nodes using a lumped-parameter formulation assuming homogeneous mixture and thermodynamic equilibrium. A momentum equation that includes the effect of wall friction and inertia is used to relate the flow rate to the pressure drop across a duct; choking is imposed on the duct flow if the conditions warrant it. A filter provides only resistance to the flow. A quasi-steady relation is imposed between the pressure head and the flow rate for a blower.

The network system models for EVENT84 are shown in Fig. 4 and Fig. 5. The inlet on the rectangular tank can be open or closed, as can the inlet on the cylindrical tank. Two arrangements were used for modeling the experiments. In Model 1, the rectangular tank inlet is open and in Model 2, the cylindrical tank inlet is open.

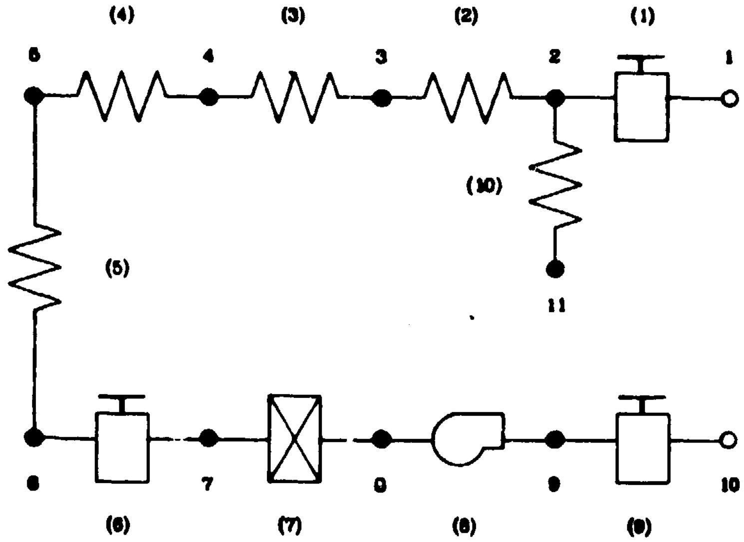

Figure 4. Computer network schematic for Model 1.

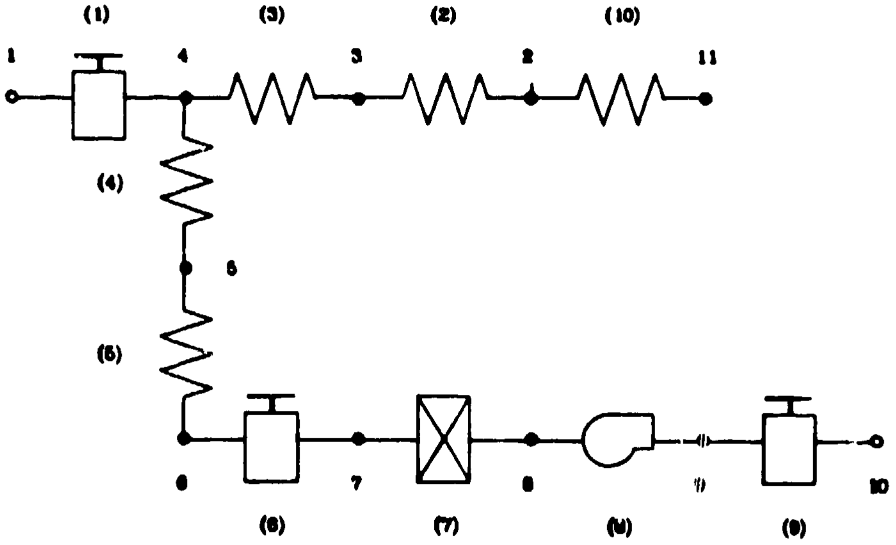

Figure 5. Computer network schematic for Model 2.

Models 1 and 2 consist of 11 nodes, including 2 boundary nodes and 9 internal nodes, and 10 branches. The symbols used on the schematic represent dampers, blowers, duct resistance, filters, and volumes of the ductwork, cylindrical, and rectangular tanks. For example, in Model 1 the numbers enclosed in parentheses represent branches and numbers without parentheses represent nodes. Branches contain blowers, dampers, duct resistance, and filters. The nodes represent points such as the explosion chamber and the cylindrical tank. Pressures and temperatures are calculated at the nodes, whereas flows are calculated for the branches.

To accurately determine the resistance coefficient for each branch, each component (the 90-degree bend, the damper, the filter, and the blower) is modeled as a separate branch. In addition, the entrance and exit for the system are modeled as dampers (branches) to account for the entrance or exit losses. The duct between the two tanks is divided into two branches to accommodate the pressure measurement. The explosions take place within a balloon in the rectangular tank. This balloon is modeled as a separate node, with a flow area into the tank equal to the surface area of the balloon. The explosion is simulated as a mass and energy input into the balloon node, either as user-calculated time functions or through the explosion chamber subroutine.

Experimental and Code Simulation Results

The experimental and code simulation results involve the following.

- Code simulations and comparison with experimental results in the explosion chamber
- Code simulations and comparison with experimental results just before the system filter
- Code simulations of pressures upstream and downstream of the filter
- Experimental results of pressures upstream and downstream of the filter

Both Model 1 and Model 2 were involved in the comparisons.

The first set of experimental and code simulation results is shown in Figs. 6 and 7. Figure 6 shows that the two methods used to simulate the explosion (EXCHAM and SOURCE TERM) over-predict the pressure within the chamber. However, the shape of the pulse is very similar. The peak pressures predicted by the code were 3.174 kPa (0.46 psi), whereas the experimental values were 1.518 kPa (0.22 psi). The peak pressure times were in good agreement. In Fig. 7, Model 2 shows similar results. That is, the peak pressures are approximately twice the values obtained from the experiment. Again, the peak pressure times were in good agreement. Closing the explosion chamber door in Model 2 increases the peak pressure by about 50%. These results were expected using the EVENT84 code. That is, the code is expected to give conservative results in areas where the explosion takes place. That is why the NF85 code has been developed--to more closely simulate explosive effects near the source.

We must point out that the experimental data were smoothed to make the information more presentable. The effect of this process was to take out the highest peaks, which were of the same magnitude as the code results. The high peaks in the experimental data are caused primarily by shock reflections inside the explosion chamber

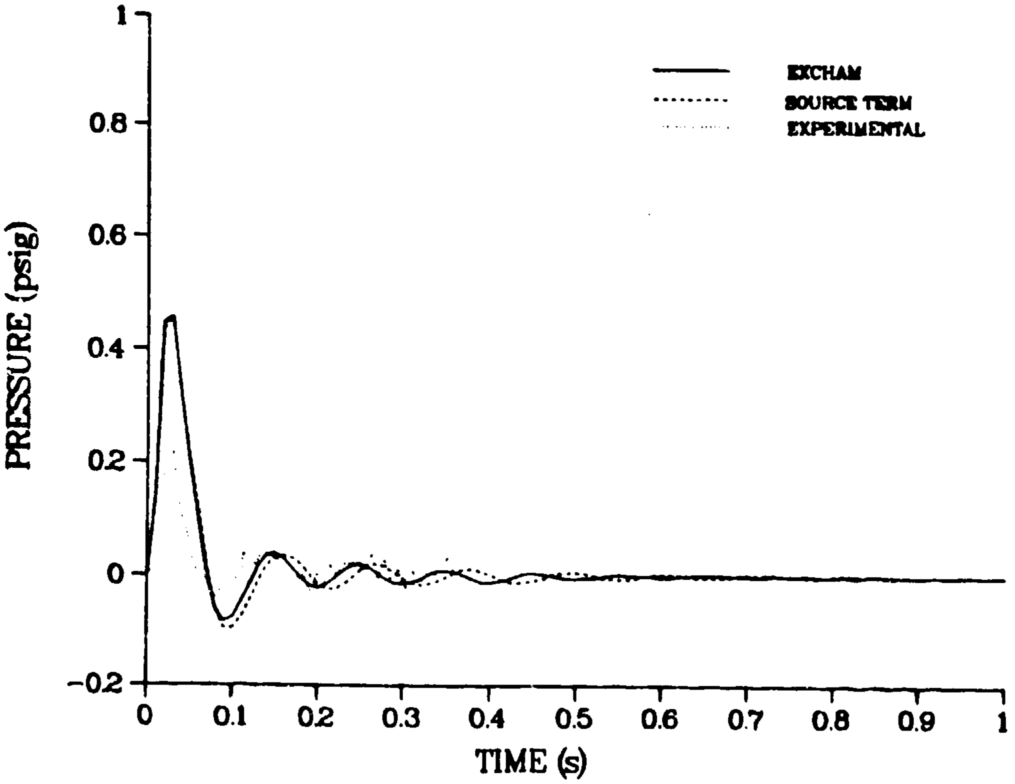

Figure 6. Code simulation of pressure in explosion chamber and comparison with experimental results (Model 1).

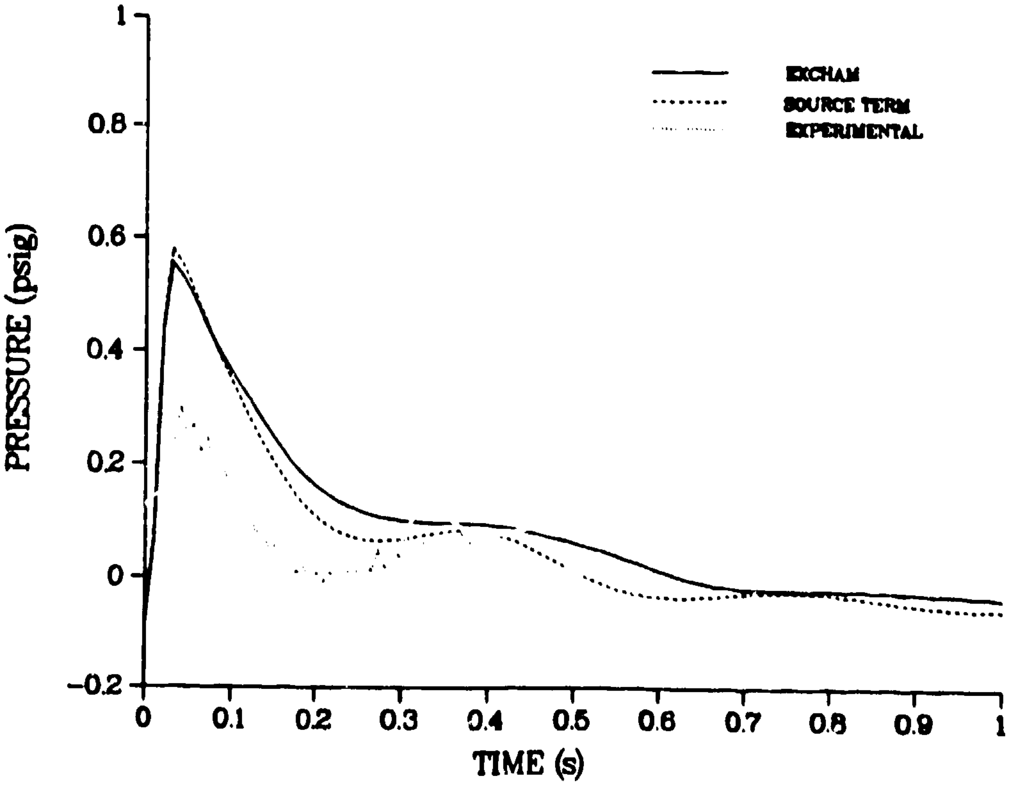

Figure 7. Code simulation of pressure in explosion chamber and comparison with experimental results (Model 2).

Pressure comparisons were made downstream of the explosion (in the chamber right before the filter). This location corresponds to node 7 on Models 1 and 2. As in the results for pressure in the explosion chamber, the code conservatively over-predicts the pressure. However, the analytical and experimental results are much closer. The time at peak pressure is much closer for Model 2 than for Model 1. As shown in Fig. 9, the peak pressure is dissipated to 1.21 kPa (1.208 psi) after passing through the ductwork and the cylindrical tank. The closer EVENT84-predicted pressure transients results supports our claim that the code predicts reasonable pressure levels in regions removed from the explosive source, particularly in areas where the final filters will be located.

Figure 10 is a plot of the pressures upstream and downstream of the filter for Model 2. As shown in Fig. 10, the effect of the filter is to essentially damp out the pressure wave. Figure 11 shows the code simulations of the pressures before and after the filter. These results indicate that the modeling does not indicate a complete dampering of the pressure wave although the peak pressure is reduced from 1.07 kPa (0.155 psi) to 0.345 kPa (0.05 psi).

Summary

Experimental verification of the EVENT84 computer code using hydrogen/air gas mixtures has been performed. The experimental apparatus consisted of two compartments with interconnected ductwork, a damper, a filter, and a blower. EVENT84's methods of simulating explosive events were compared with pressure transients obtained in the explosion chamber. The code predicted results that were conservative by a factor of 2. Comparison of pressure at the system's filter indicate good agreement with the experimental data. Experimental and analytical results show that the effect of the filter is to dampen the pressure wave as it passes through the filter.

Future experiments will use solid explosive and be expanded into a much larger system. These experiments will also use a simulant radioactive aerosol for material transport data.

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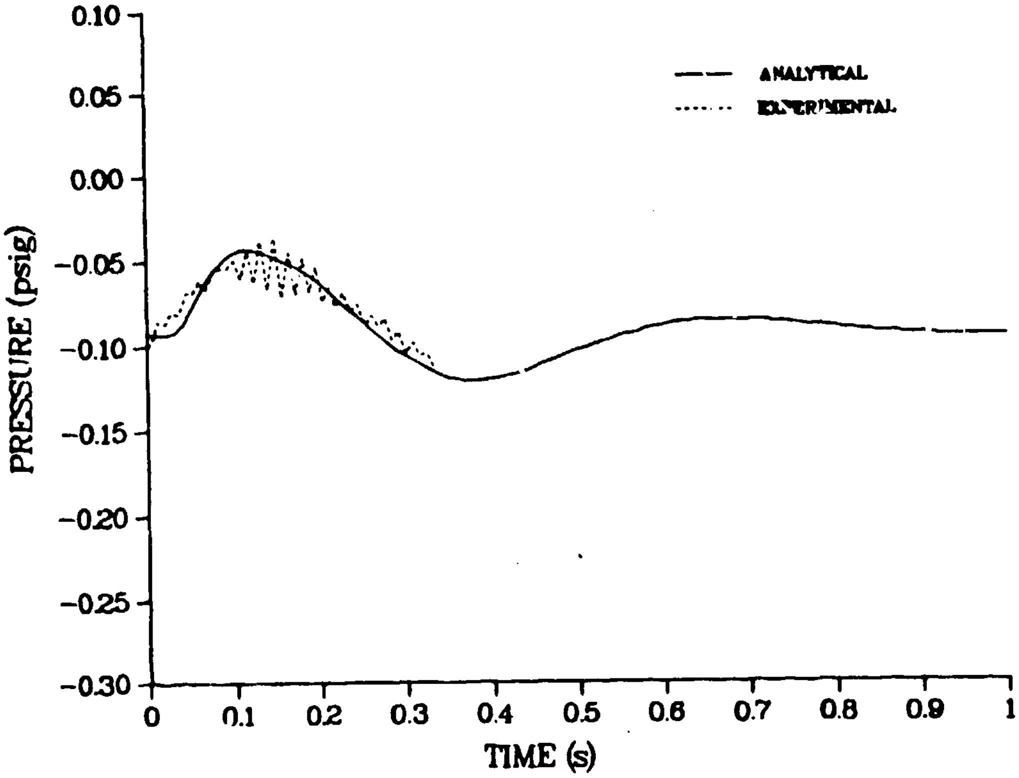

Figure 8. Code simulation and experimenal results of the pressure just before the filter in Model 1.

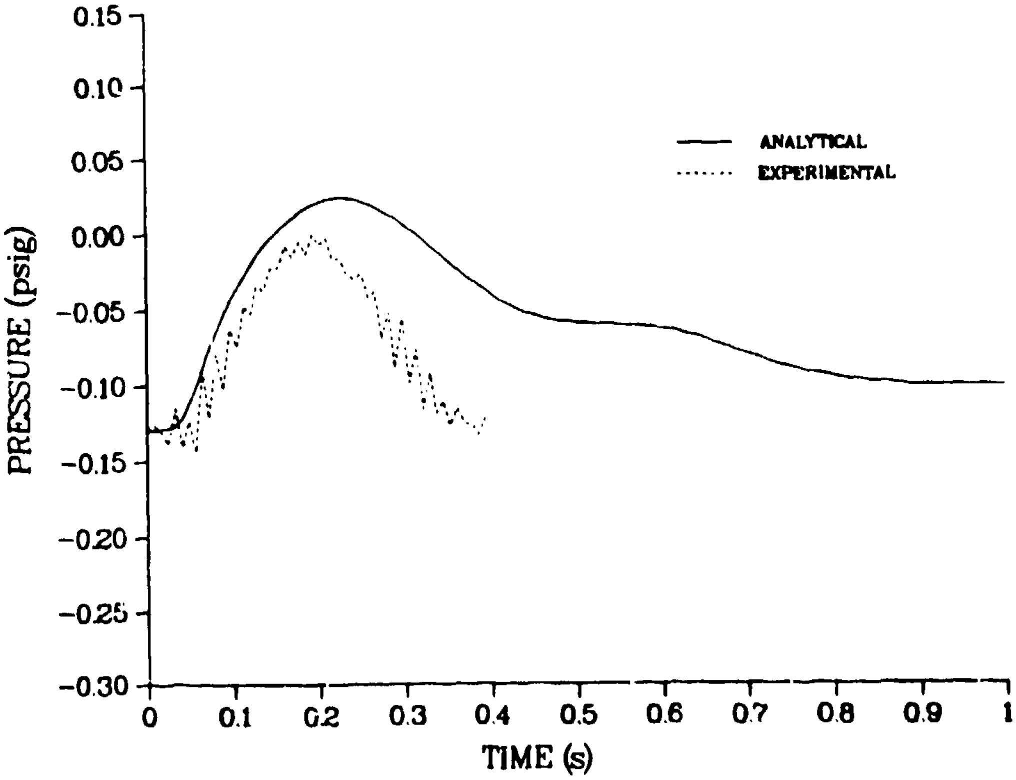

Figure 9. Code simulation and experimental results of the pressure just before the filter in Model 2.

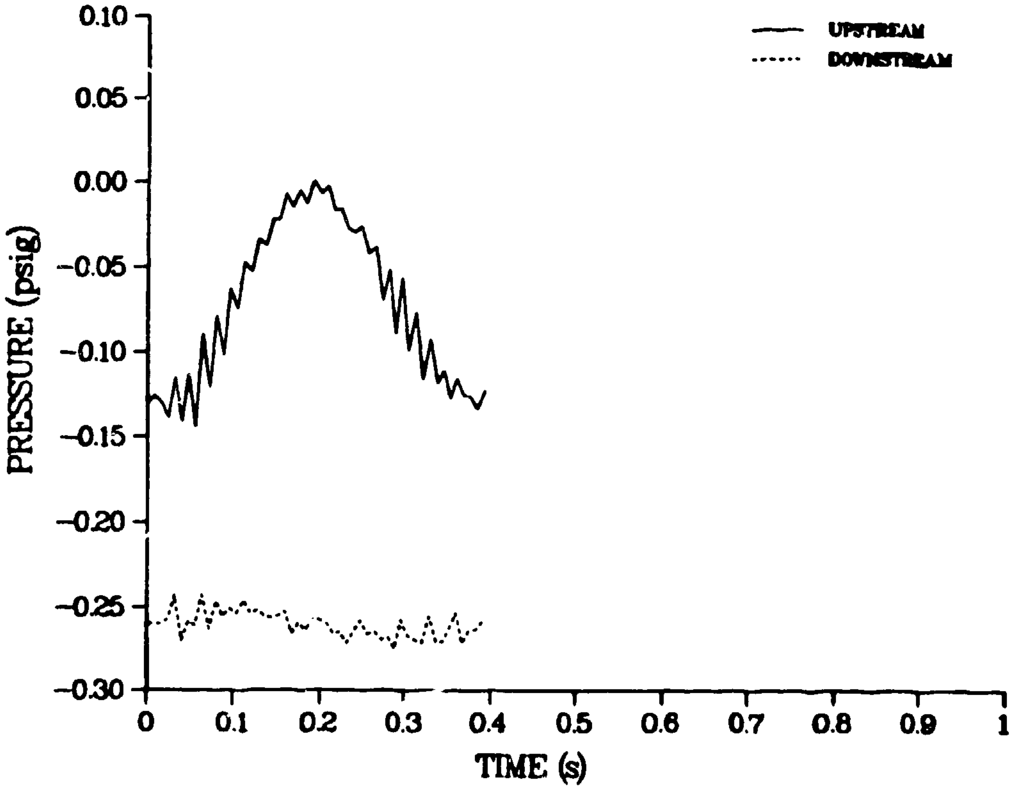

Figure 10. Experimental results for transient pressures upstream and downstream of the filter (Model 2).

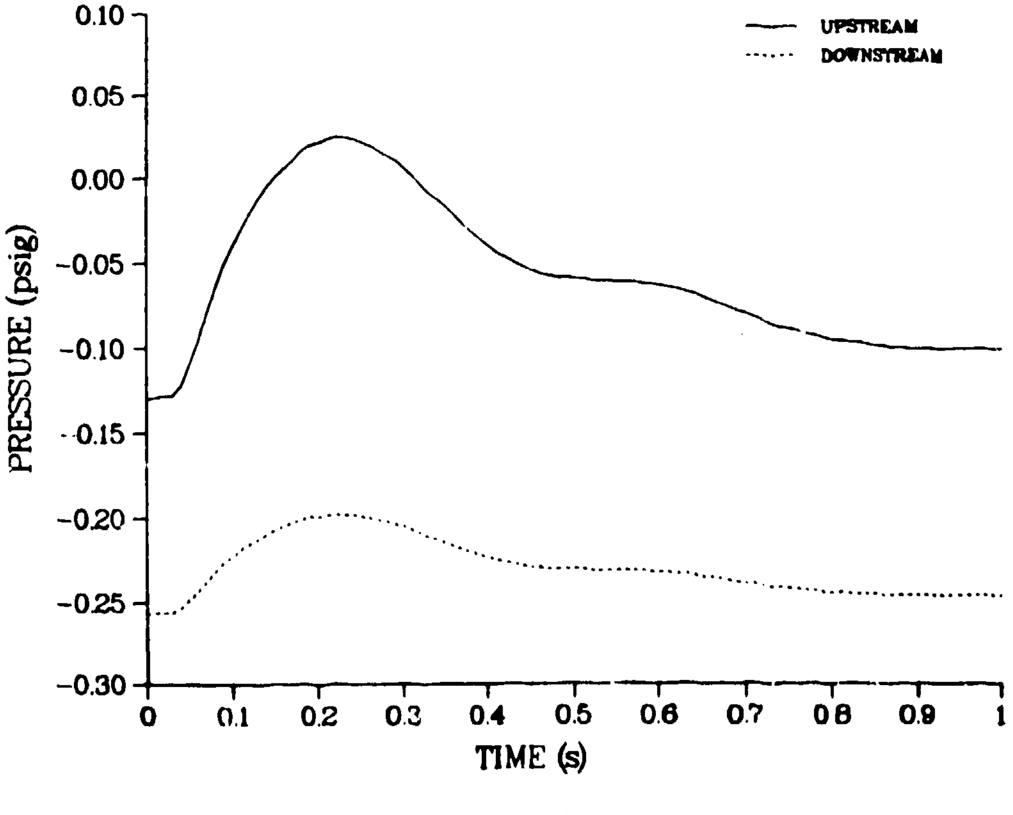

Figure 11. Code simulation results of pressures upstream and downstream of the filter (Model 2).

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Keywords

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- Computer Codes
- Air Cleaning Systems Analysis
- Experimentation