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B-18-64

A FAST RUNNING MODEL FOR ACCURATE TIME-DEPENDENT POST-SHOCK GAS FLOW

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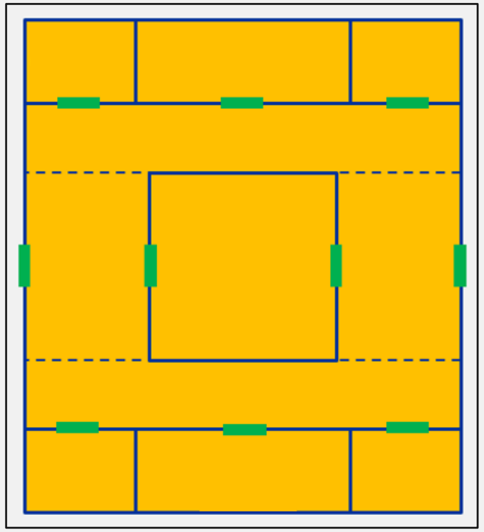
Presented to:
Internal Explosives Safety Symposium & Explosion (IESSE) Conference
Wednesday, August 8th

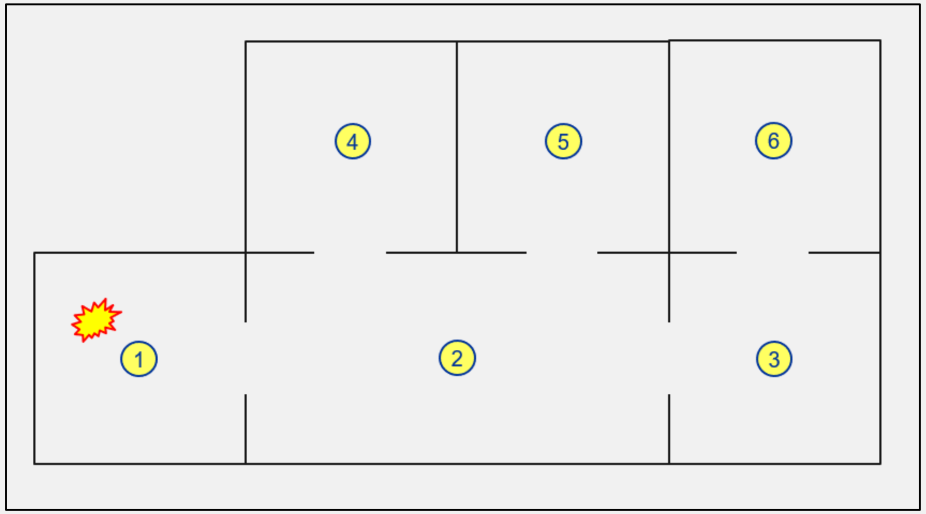
OUTLINE

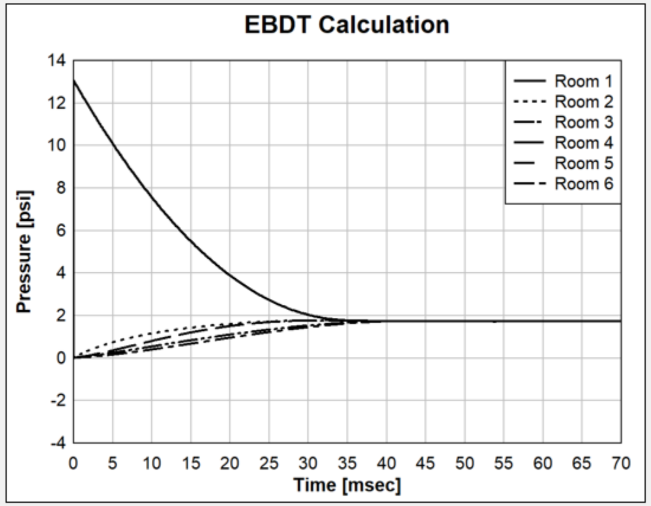
- 1) Introduction
- 2) Theoretical Model for Gas Pressure Application
- 3) Results and Comparisons
- 4) Conclusions

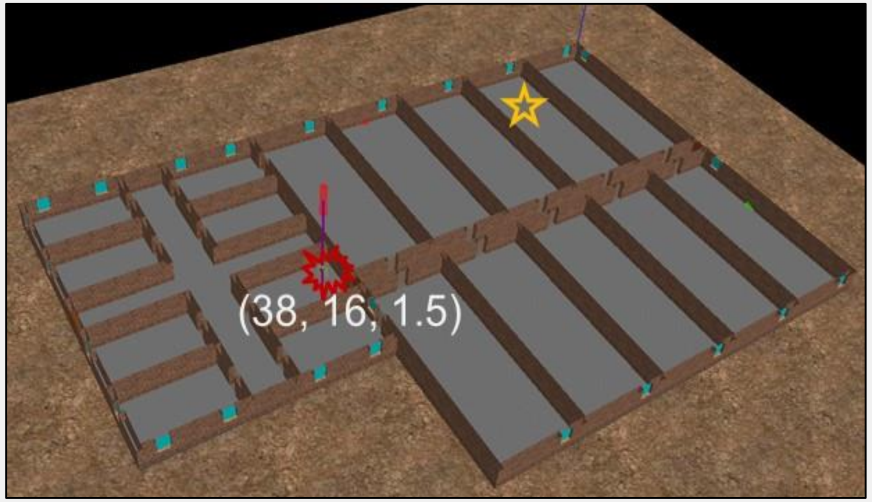
PART I: INTRODUCTION
MOTIVATION

- **Limitations of current airblast gas solvers for confined explosions**
  - *Tools designed for simple geometries*
    - Cubed shaped rooms with nozzle sized vents
    - Typically accurate for only one to two rooms
    - Simplified assumptions do not always produce realistic gas pressure profiles
  - *Tools designed for non-responsive surfaces*
- **Actual explosive handling facilities**
  - *Hallways, multiple rooms, frangible panels, etc…*

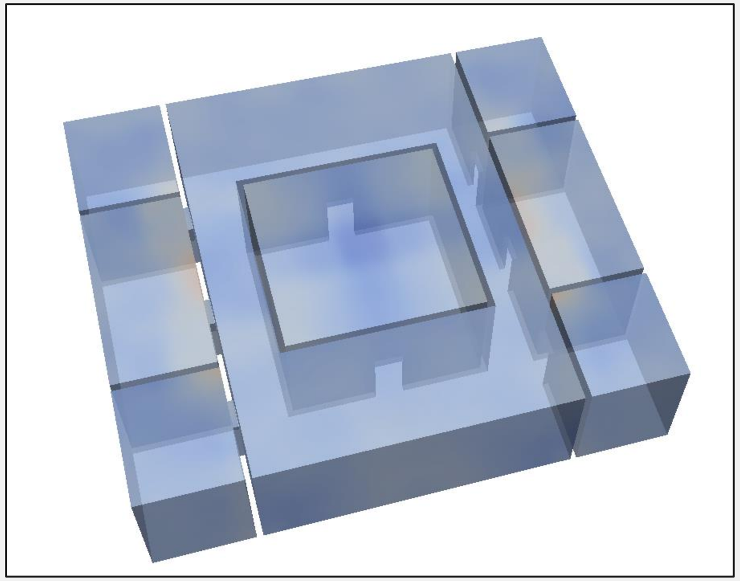


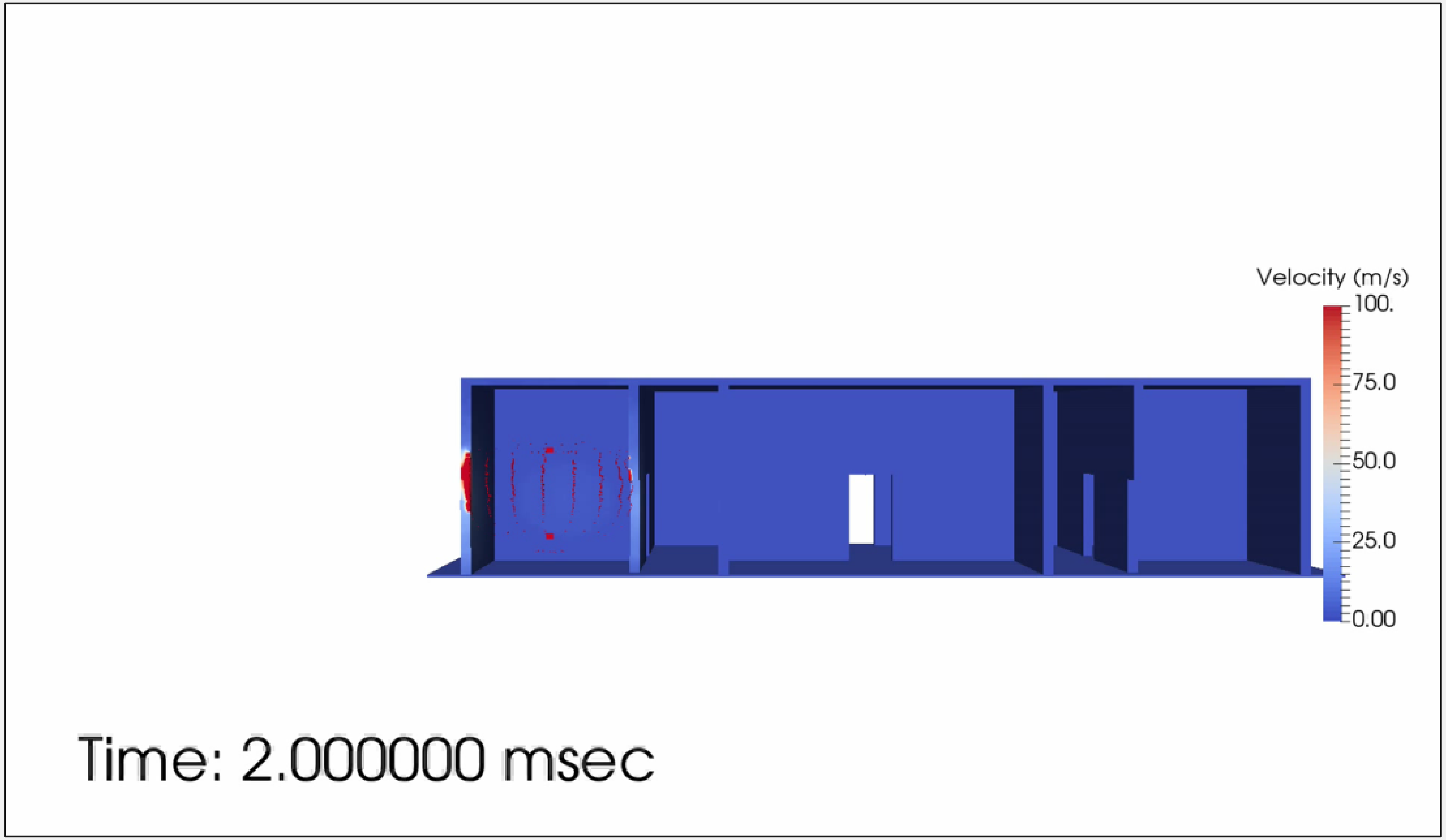






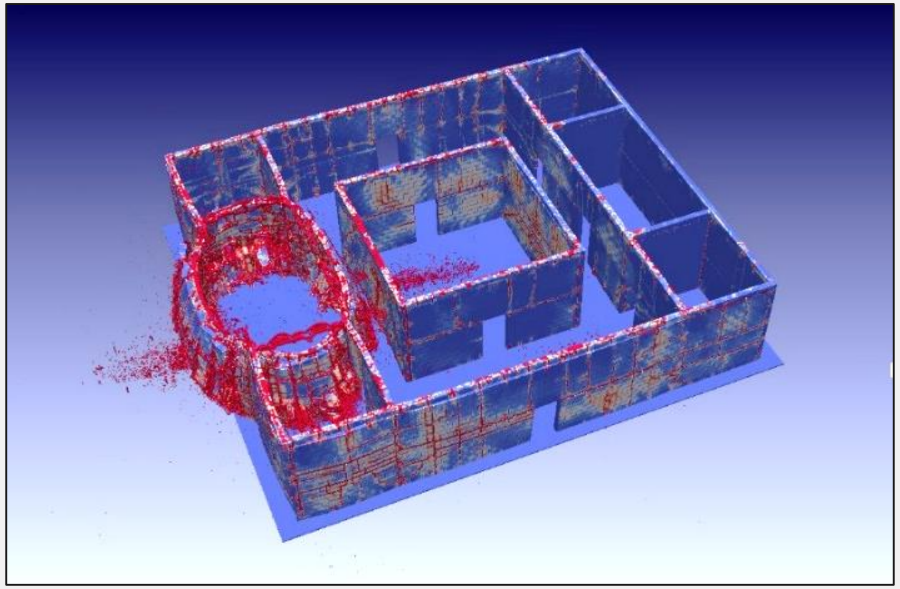
MOTIVATION

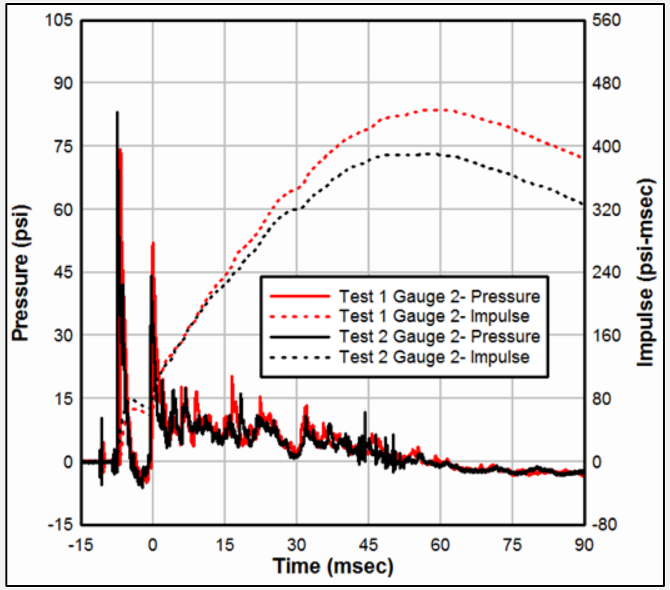


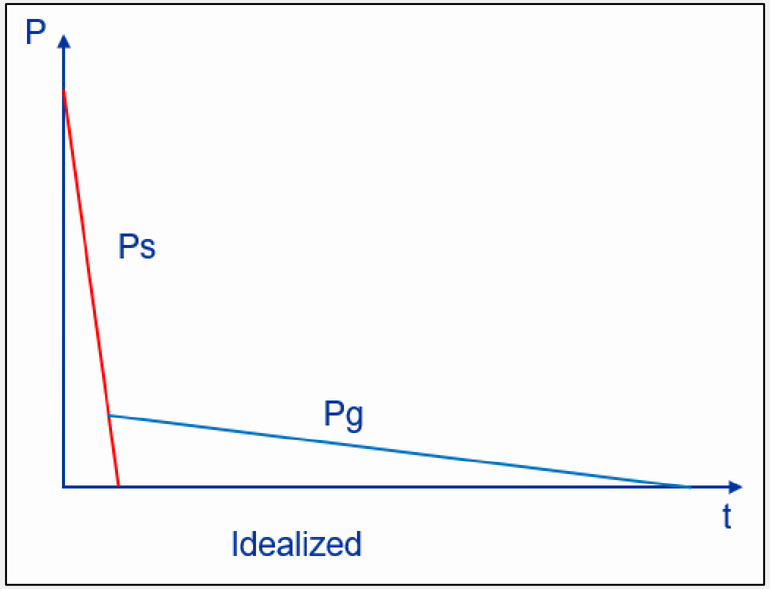


BACKGROUND

- For confined environments, the blast pressure waveform can be simplified into two different regimes:
  - *Shock pressure*
  - *Gas pressure*
- The shock and gas loading regimes have different peak pressures and occur over varying time scales:

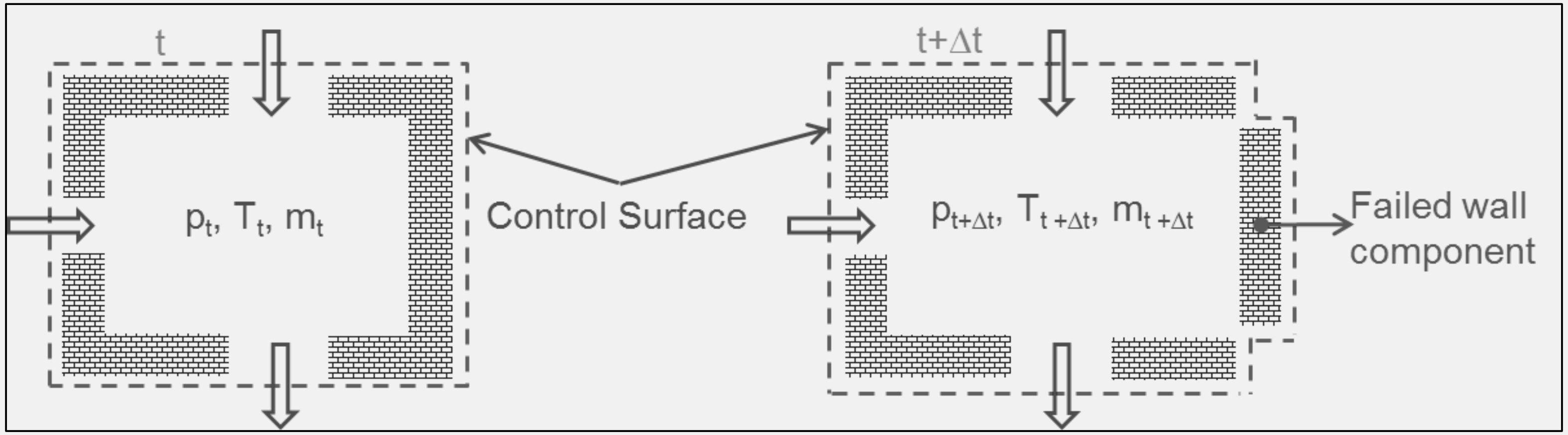






PART 2: THEORETICAL MODEL FOR GAS PRESSURE APPLICATION

- A new gas pressure solver is developed to address limitations with existing codes
- The solver is based on a control volume approach
- Control volume is a volume in space that encapsulates an area of interest
  - *Size and shape can be arbitrary*
  - *Mass and thermodynamic properties inside the control volume can change with time*
- The surface of the control volume is referred to as a control surface
  - *Surface can be fixed or it may move so that it expands and contracts*
  - *Mass, heat, and work can cross the control surface*

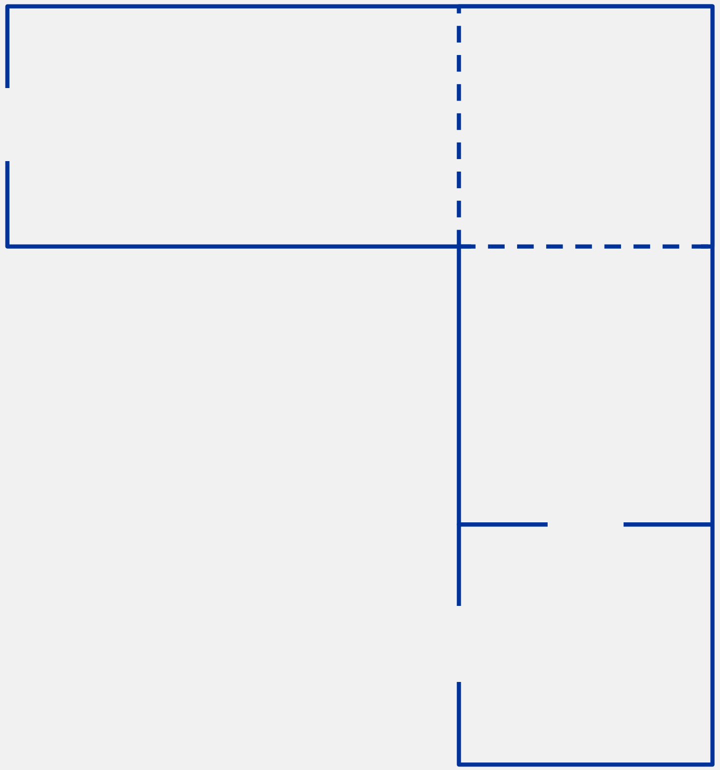


GFLOW-MODULE METHODOLOGY

- Global conservation of mass and energy are enforced every time-step:
  - $\frac{dm}{dt} = \sum \dot{m}_i - \sum \dot{m}_e$
  - $\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_i(e_i + P_i v_i) - \sum \dot{m}_e(e_e + P_e v_e)$
- Currently, ideal gas equation of state is implemented
- Specific heat for air is treated as a function of temperature
  - $C_v = f(T)$

INNOVATIVE VENTING PROCEDURE

- Two different vent methodologies
  - *Nozzle equations for small openings*
    - Classical approach found in all airblast gas solvers
    - Subsonic and transonic treatment (choked flows)
    - Produces accurate results for applicable geometries and configurations
  - *Control volume momentum conservation for large openings*
    - Solves global conservation of momentum equations
    - Equilibrates multiple rooms faster than the nozzle approach
- Automated procedure for vent method selection
  - *In the case the opening is bigger than 50% of the total wall surface, the conservation of momentum approach is used*
  - *Otherwise, the nozzle equations for small openings are used*



NOZZLE FLOW FOR VENTS

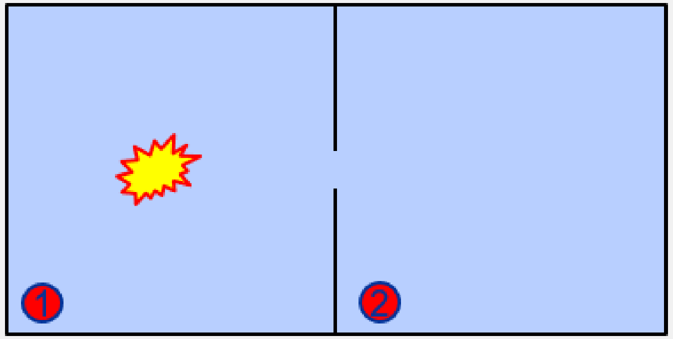
- Nozzle equation: isentropic steady-state compressible flow equation for calculating the venting velocity
- It applies only to small vents where chocked flow is expected

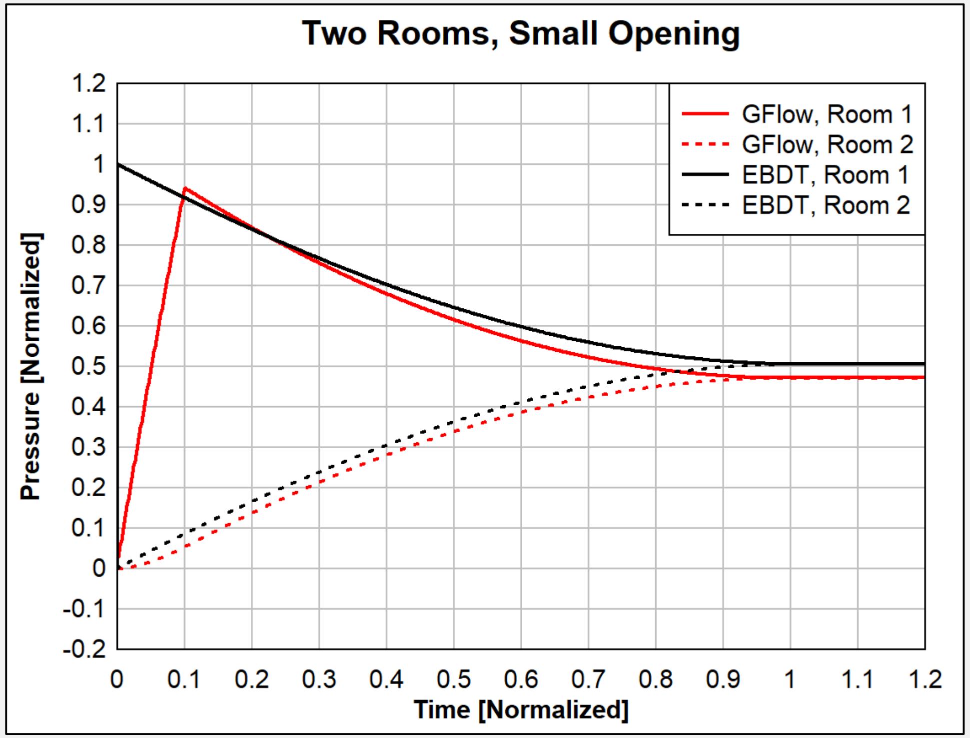
Mass flow Equation

$$\dot{m} = \left(\frac{\gamma MAP}{c_s}\right)_2$$

Choked Condition

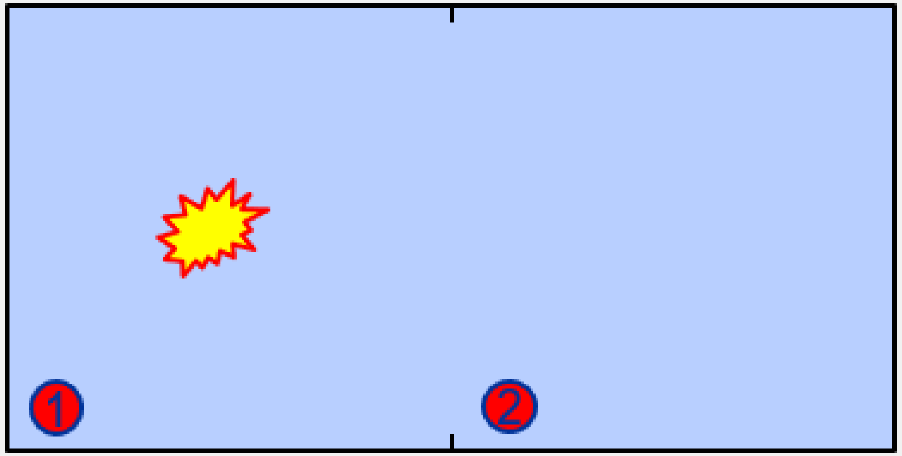
$$\left(\frac{P_2}{P_1}\right)_c = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma - 1}}$$

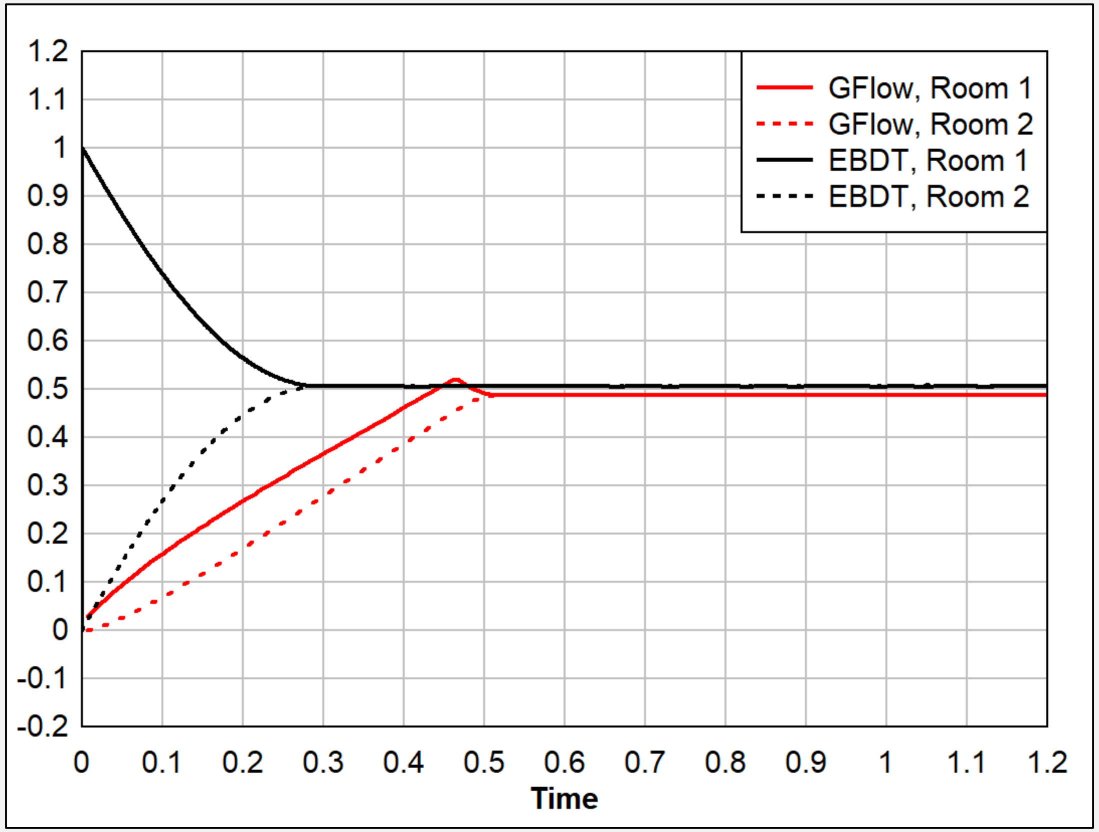




EQUATIONS OF MOMENTUM FOR BIG OPENINGS

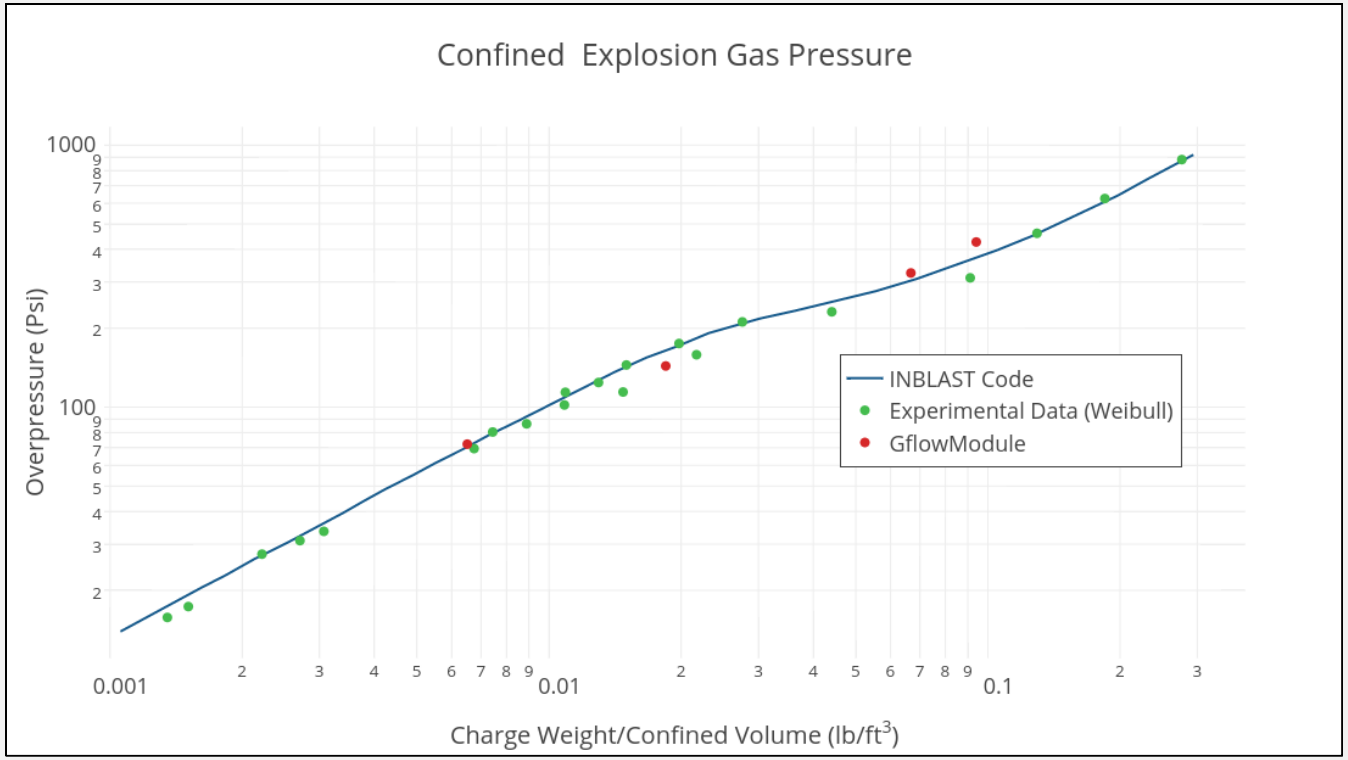
- Conservation of momentum equations
  - $\frac{d(mV_x)}{dt} = \sum F_x + \sum \dot{m}_i V_{ix} - \sum \dot{m}_e V_{ex}$
  - *Brings pressure in both rooms to equilibrium almost instantaneously*
  - *Solve the global equilibrium of momentum for all the rooms involved in the venting process*





VALIDATION OF PEAK GAS PRESSURE

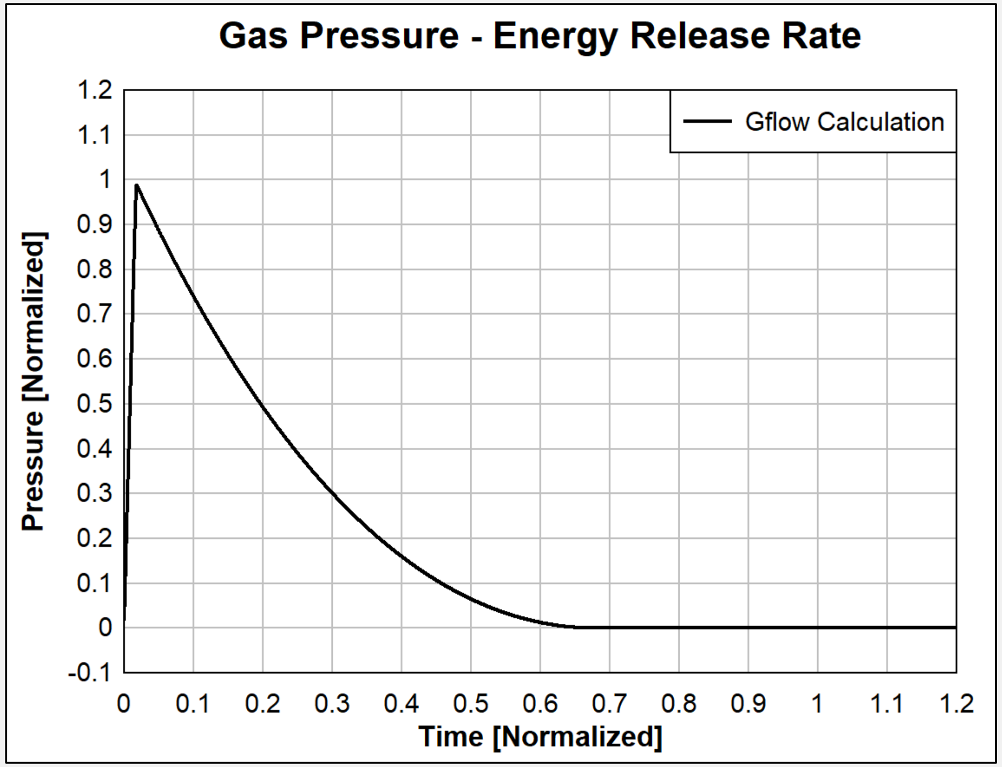
- Chemistry and energy release model
  - *Total energy yield computed based on C, H, N, O composition of the explosive and oxygen in the detonation room*
  - *Specific heat as a function of temperature for the gas in the room*
  - *Combustion Reaction:* $C_xH_y + zO_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$



- Weibull, H. R. W., "Pressures Recorded in Partially Closed Chambers at Explosion of TNT Charges (U)", Annals of the New York Academy of Sciences, Vol. 152, Art. 1, pg. 357, 1968

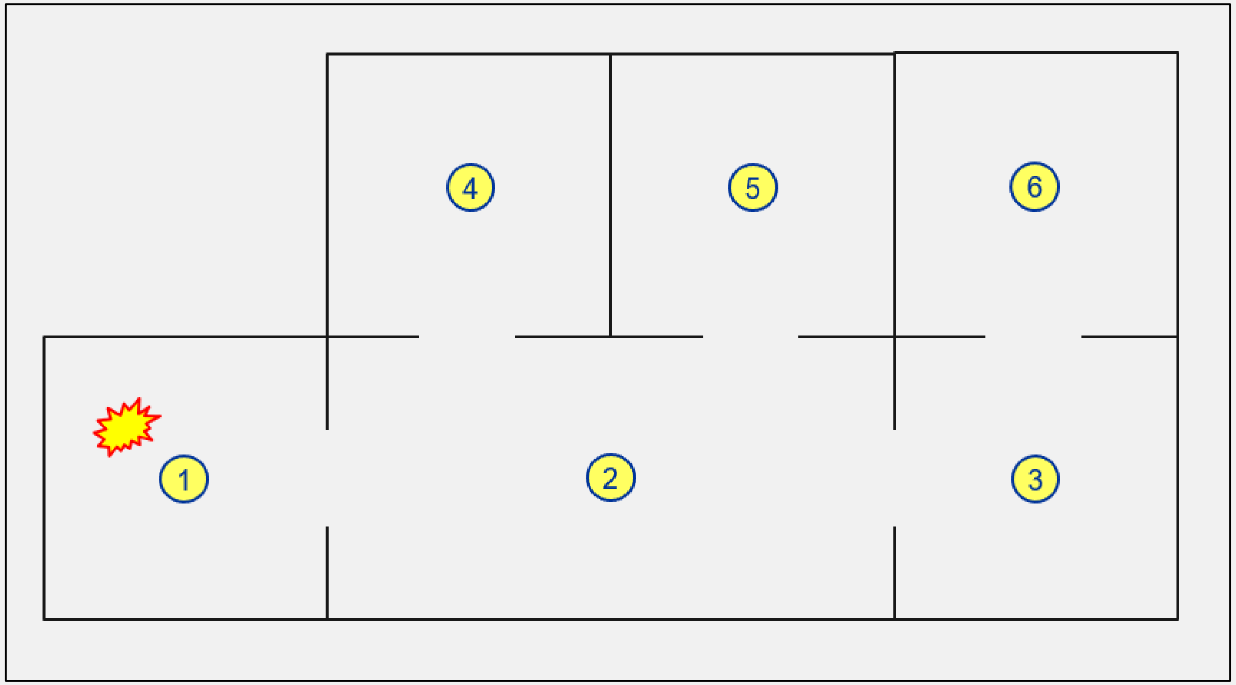
GAS PRESSURE RISE-TIME

- Gas pressure rise-time
  - *Gas pressure rise-time is a function of the geometry and it does not reach the maximum value instantaneously*
  - *Achieved by computing the energy release rate based on room size*
  - *The rise-time is calculated based on a characteristic length of the room and the speed of sound:*
  - $t_r = \frac{L}{c_s}$
  - *MBLM Approach:*
  - $t_x = max\left[0.005\left(\frac{m_s}{250}\right)^{1/3}, \frac{V_R^{1/3}}{1000}\right]$
  - $dE/dt = (1 - f_f)m_s H_{ex} t_x$



PRESSURE VENT TIME

- In the application the target is defined by rooms and connections (i.e. vents)
- Problems that arise with instant equilibration of pressure:
    1. *Venting is starting simultaneously in all the rooms*
    2. *Venting to rooms 4, 5, and 3 occurs at the same time which leads to a pressure equilibrium on the wall between 4 and 5.*



CALCULATION OF DELAY ON OPENINGS

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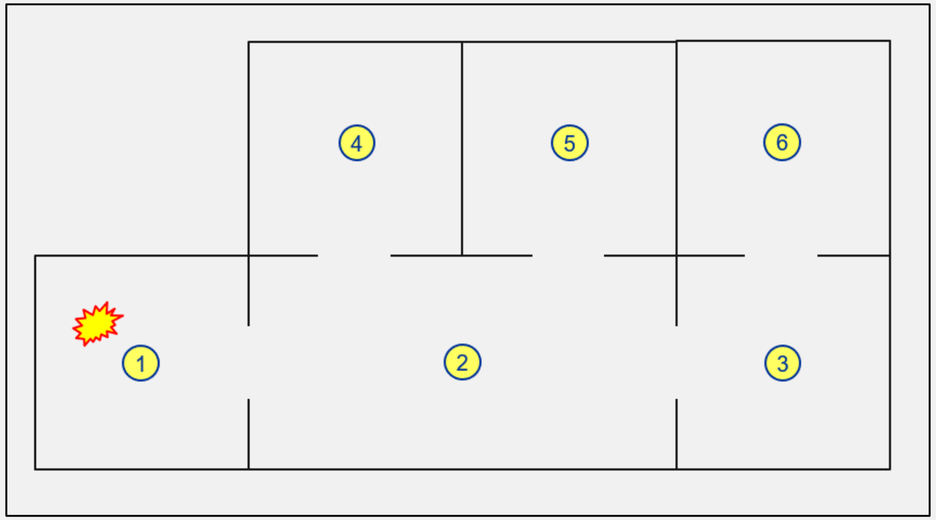
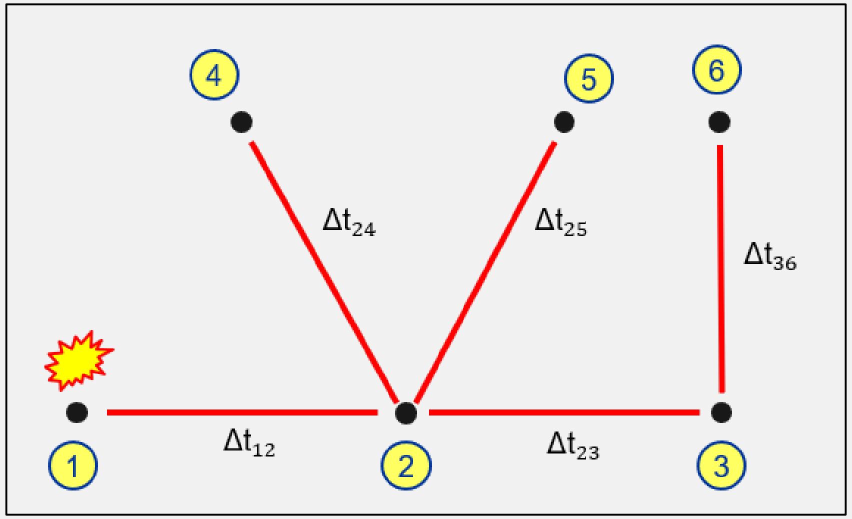
- The pressure wave requires time for travelling from one room to another
- The time for the pressure to propagate to a room is calculated based on its distance from the charge (point of detonation)
- The pressure wave speed corresponds to the speed of sound. Δt is then calculated to "delay" the opening of vents





VENT TIME BASED ON VENT LOCATION

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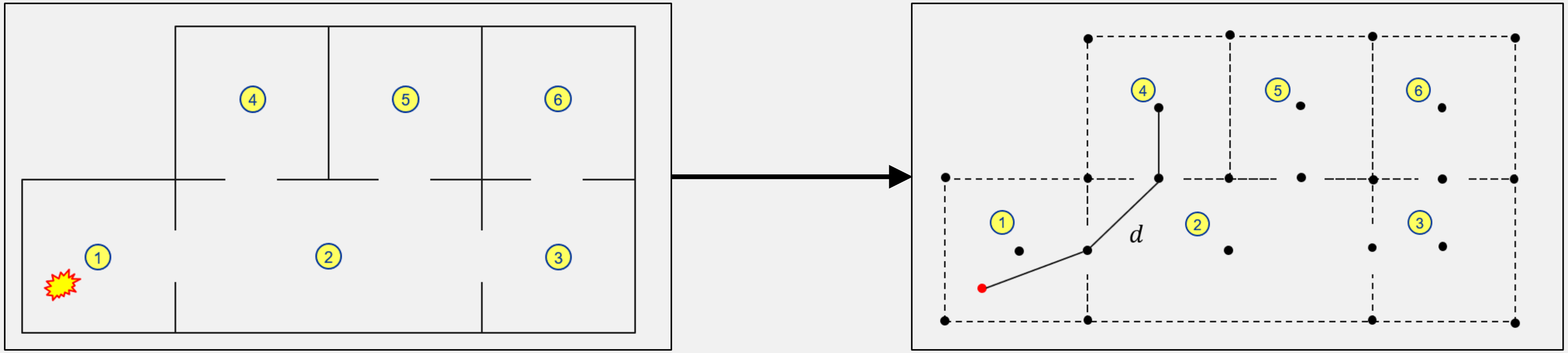
- A connectivity network approach has been developed for calculating all the possible paths the pressure can travel
- That allows the code to accurately calculate the vent activation time based on its physical location (e.g. the distance of the room from the detonation location)
- Using a network of nodes and connections, Dijkstra’s algorithm is used to calculate the length of each path as well as the shortest path between any two rooms



BUILDING WITH HALLWAY

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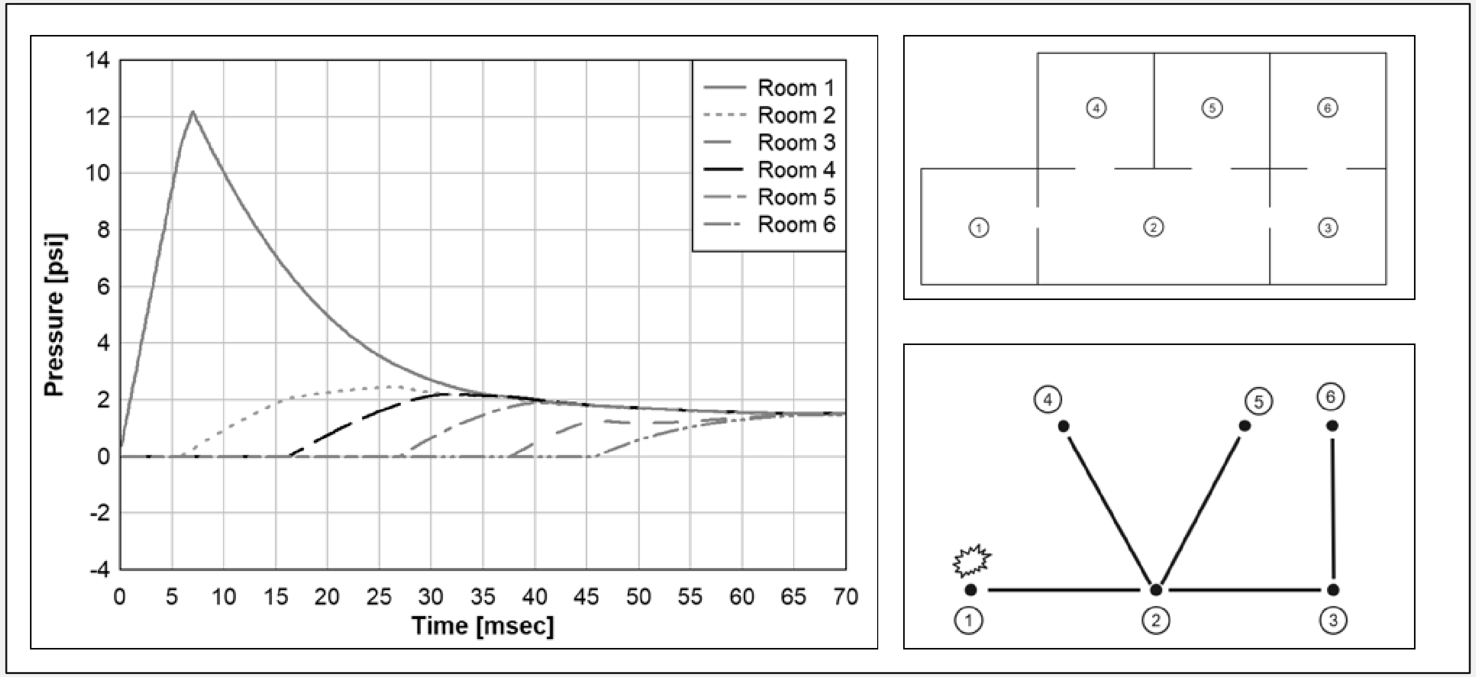
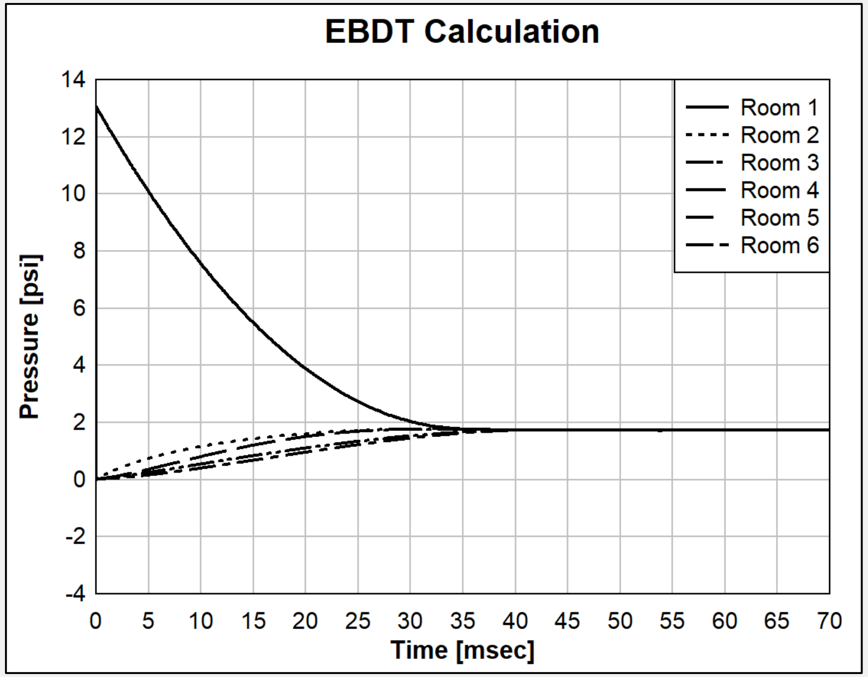
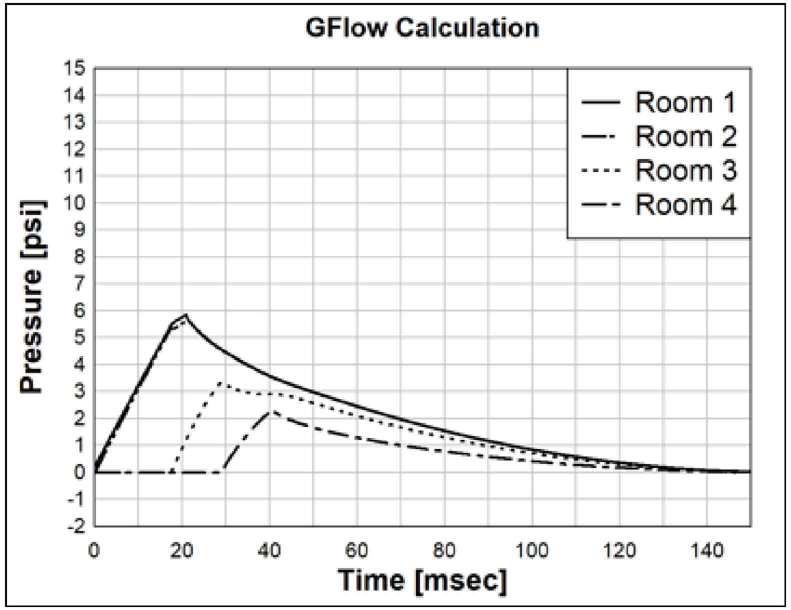
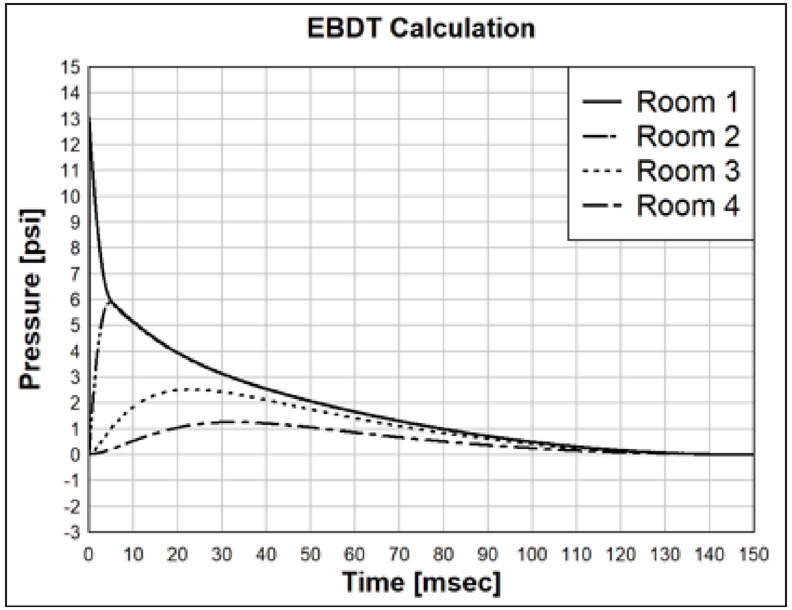
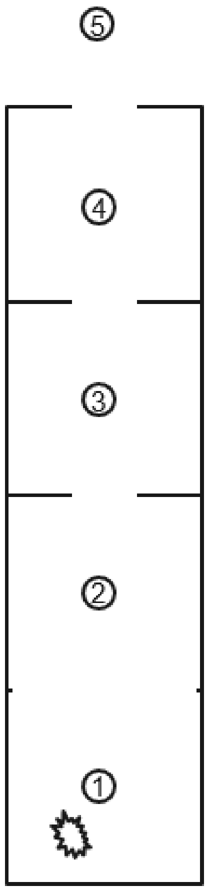




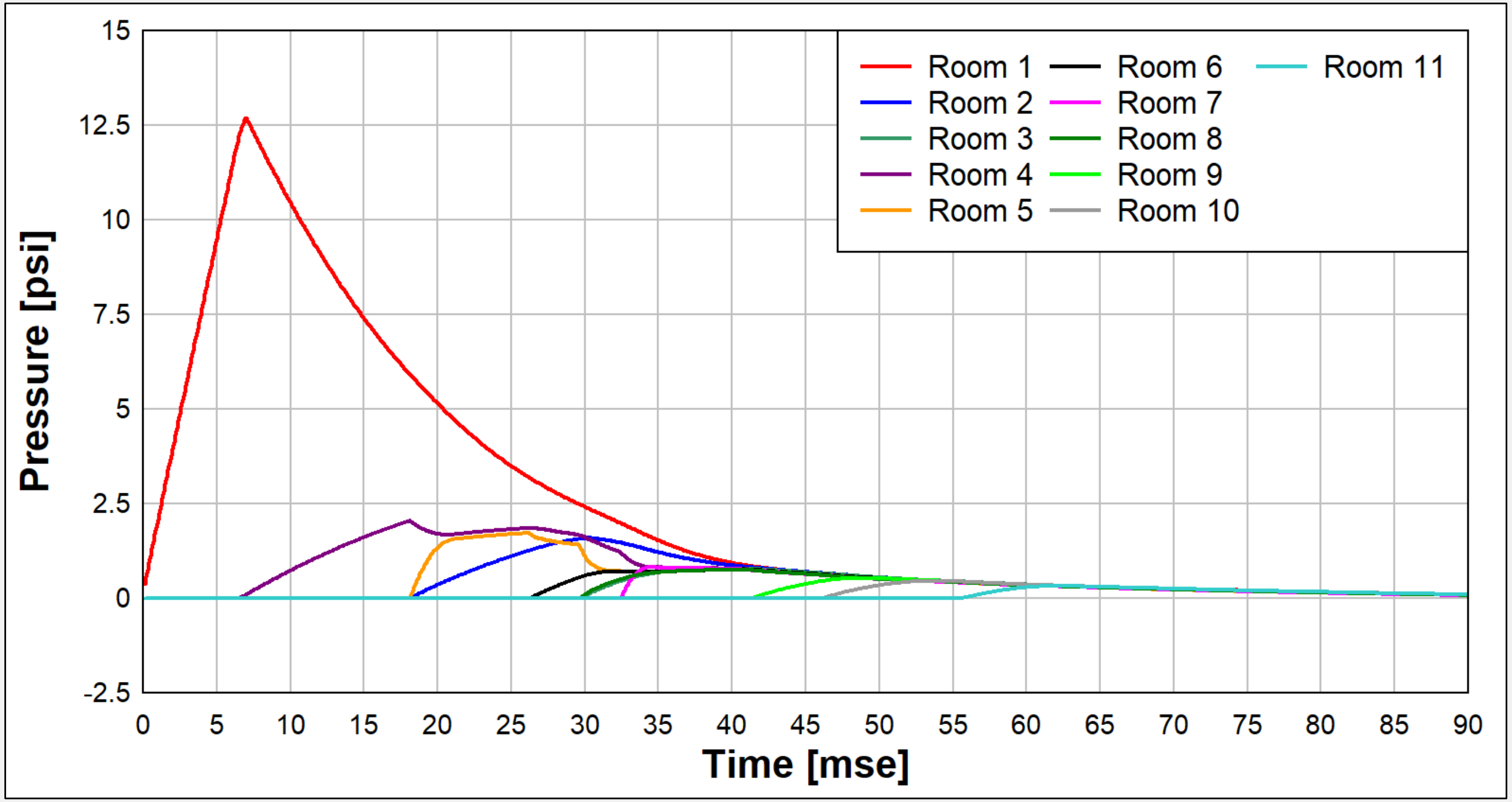
PART 3
RESULTS AND COMPARISONS



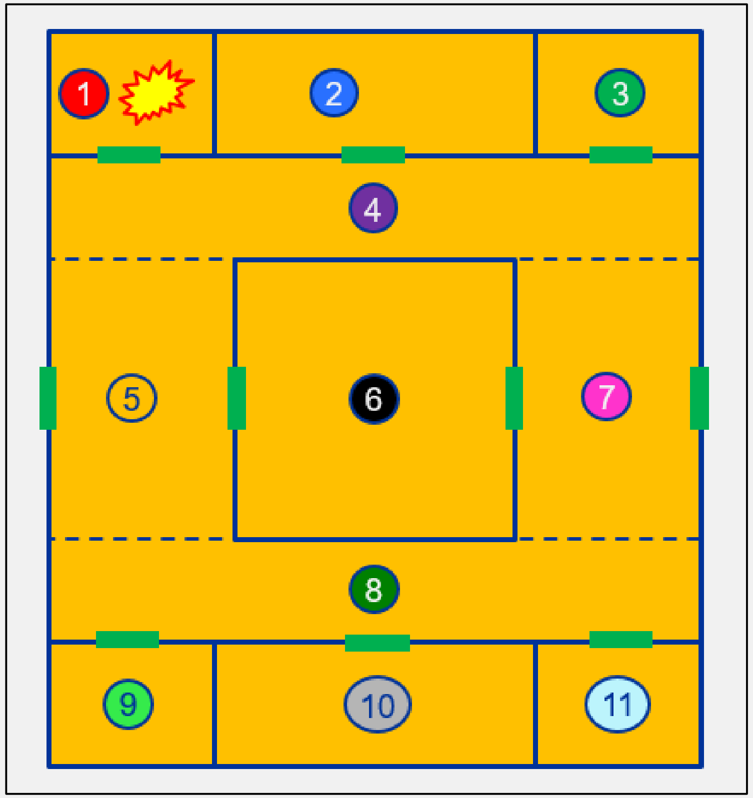




COMPLEX STRUCTURE



Detonation in Corner Room



PART 4
CONCLUSIONS

- A novel methodology for the prediction of blast effects in confined environments has been developed.

- It introduces a technique that combines two algorithms for solving the transport of properties across rooms.

- The model also considers the spatial distance of each vent from the burst point to compute a delay time for the activation of each vent.

- The model provides more realistic pressure profiles for complex facilities, still remaining a fast engineering tool.