Codes and Standards Analysis

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Abstract

The following report contains work on three separate tasks. They are as follows:

Task A -- Safety Analysis of California Fuel Cell Partnership Building
Task B -- Development of Method to Determine Hydrogen Sensor Placement
Task C -- Safety Analysis for writing of codes

The work in Task A is an analysis of the existing system and procedures that deal with hydrogen leakage from hydrogen fuel vehicles. The work in Task B is the development of and method for producing helium filled bubbles to visualize hydrogen gas motion in enclosures. The work in Task C was divided into two of additional areas. They are as follows:

Area 1 -- Analysis of hydrogen flame impingement on gypsum board.
Area 2 -- Computer modeling of hydrogen leakage to assist in writing International Mechanical Code for ventilation and setbacks.

Introduction

The goals and objectives of this work effort were developed anticipating the needs of various projects and authors of codes and standards. This work addresses potential safety concerns, due to hydrogen leakage, in three areas of hydrogen utilization. These safety concerns affect the widespread use of hydrogen in the private sector.

Task A – CaFCP Building Safety Analysis

Task A addresses six questions concerning the CaFCP building in Sacramento CA. They are as follows:

1. Should the garage door be opened when hydrogen is detected in bays with the garage door located on the west side of the bay (Toyota, Nissan, Daimler-Chrysler)?
2. What happens if a pressure relief device (PRD) release occurs in close proximity to the air conditioning return duct?
3. Can restrictions be placed on vehicle location to allow a PRD release without hydrogen entering the air conditioning return duct?
4. What can be done to air conditioning return duct location to reduce risk during an accidental PRD release?
5. What is the severity of ignition of hydrogen leaking into a 5000 square foot bay?
6. What is the severity of accidental ignition of hydrogen leaking under a large vehicle?

Two hydrogen leakage scenarios were investigated. The PRD release was assumed to empty all of the fuel in the tank, with the flow rate decaying exponentially, in 100 seconds. The non-PRD leakage rate was set at 80 SCFM hydrogen. This was chosen because it represents a reasonable maximum flow rate above which an excess flow valve mounted in the tank would be activated. In addition, there would have to be multiple safety system failures to produce an 80 SCFM hydrogen leak.

An analysis was done to determine what would be the result of an 80 SCFM leak from a hydrogen fueled vehicle parked close to the garage door. This was done because the initial hydrogen detection protocol called for opening of the garage door when hydrogen was detected in the bay. Since the motor for the roll-up door was not a brushless motor, or a "totally enclosed fan cooled" device, it could be an ignition source in the event of a hydrogen release. The analysis was done for bays that have garage doors on the west side of the bay (Toyota, Nissan, Daimler-Chrysler). Bays with the garage door located on the east side of the bay had been previously investigated.

The accident scenario with the most severe outcome occurred when a vehicle was pulled just inside the bay and the garage door was closed.

After 16 seconds of hydrogen leakage the first sensor reached 20% of the lean flammability limit (LFL), which is 0.82% hydrogen concentration (Figure A1). In the following second, the sensor reached 40% of the LFL (1.64% hydrogen concentration). The hydrogen sensor triggers a safety protocol that activates increased exhaust flow and other safety measures. One such safety measure is opening the large bay door. Whether the protocol calls for activation at 20% or 40% of LFL, the earliest the door can begin to open is after 16 seconds of leakage. At that point the motor is surrounded by a burnable mixture of hydrogen and air at 100% LFL (Figure A1). Since the motor is an ignition source the burnable cloud in figure A1 represents the minimum cloud size to be ignited. Opening the garage door takes 23 seconds. Possible sensor delay times of three to four seconds would increase the size of the cloud before ignition. If the garage door is not opened and the cloud is not ignited, the accident scenario continues as shown in figure A2. The increased exhaust flow rate reduces the size of the 100% LFL cloud below that which would exist if the standard exhaust flow continued. The reduction in the size of the 100% LFL cloud due to the increased exhaust flow continues until the protocol is the deactivated, which occurs after the tank is empty.

The question of pressure release device (PRD) failure was initially addressed by assuming to 1.1 kg (2.5 lbs) of hydrogen was stored on the vehicle and that it escaped through the PRD in 100 seconds. The vehicle was located as close to the air conditioning return duct as possible.

Figures A3 and A4 show a PRD release of 2.5 lbs of hydrogen with the air conditioning system operating. Hydrogen would be drawn into the air conditioning system. Figure A3 shows that gases richer than 4.1% hydrogen concentration have filled the air conditioning system in the first ten seconds of leakage. This is prior to any procedural attempt to turn off the air conditioning system when the first sensor reaches 0.82% hydrogen concentration. The first sensor reaches 0.82% hydrogen concentration in ten seconds triggering an exhaust flow rate increase from 2100 SCFM to 6300 SCFM. This increases the makeup air flow rate and reduces hydrogen concentration in the air conditioning system below 4.1% even though hydrogen at greater than 4.1% concentration is entering the system. Figure A4 shows the burnable hydrogen cloud covers half of the ceiling at 30 seconds and disappears by 100 seconds when the hydrogen leakage stops.

Figure A5 shows the growth of the 4.1% hydrogen concentration cloud for a PRD release of 1.1 kg (2.5 pounds) of hydrogen with the release occurring 14.6 m (48 feet) away from the air conditioning inlet. Clouds at 10 and 20 seconds are shown. The sensor triggers an increase an exhaust flow rate from 2100 CFM to 6300 CFM at 2 seconds. Even if the air conditioning fails to shut off, the cloud of 4.1% concentration hydrogen does not reach the air conditioning inlet. At 14 seconds it is within 4.5 feet of the inlet and then begins moving away. Placing the leak several feet closer to the inlet would result in the 4.1% concentration hydrogen reaching the inlet. Figure A6 shows the decrease in the size of the 4.1% hydrogen cloud with time.

Figure A7 shows the 0.82% and 4.1% concentration hydrogen clouds at 10 and 30 seconds after a PRD release of 2.5 pounds of hydrogen. The air conditioning inlet vent had been lowered 2.44 m (8 feet) from its original position. The 4.1% hydrogen concentration cloud was within inches of the air conditioning inlet at 10 seconds. This occurred with the exhaust flow rate being increased from 2100 CFM to 6300 CFM at 10 seconds. It was assumed that the air conditioning malfunctioned and continued to draw 4400 CFM of air throughout the run.

Figures A8 through A11 show results for a 5.0 kg (11.0 lb.) PRD release with the air conditioning return duct lowered 2.44 m (8.0 ft). The air conditioning flow rate is held constant at 4400 SCFM but the exhaust is increased to 6300 SCFM at 5 seconds. This assumes a failure to shut off the air conditioning but no failure to increase the exhaust flow rate. Figure A8 shows the results after 5 seconds of hydrogen leakage. The first sensor has reached 40% LFL (100% LFL shown in red, 25% LFL shown in blue). Burnable hydrogen (red) has not reached the return duct but 25% LFL (blue) has reached the duct. Figures A9 and A10 show the results at 10 seconds and 20 seconds. Burnable hydrogen has not entered the air conditioning system. Figure A11 shows the results after 80 seconds of hydrogen leakage. This is the point of highest hydrogen concentration levels. Burnable hydrogen has not entered the air conditioning return duct but gases in the air conditioning system are richer than 25% LFL (blue).

Figures A12 through A14 show the results of both a failure to shut down the air conditioning system and a failure to increase the exhaust flow rate. The exhaust flow rate remains at 2100 SCFM for the entire event. Figure A12 shows concentration contours at 10 seconds, figure A13 at 20 seconds and figure A14 at 80 seconds. Once again though 25% LFL (blue) hydrogen enters the air conditioning system the hydrogen concentration in the system does not reach 100% LFL.

Figure A15 shows the difference that the higher exhaust flow rate made viewed at 100 seconds. The change due to increased exhaust flow rate that occurs at 5 seconds increases with time. The red contours are 100% LFL at the increased exhaust flow rate (6300 SCFM). The blue contours are 100% LFL at the original exhaust flow rate (2100 SCFM). It can be seen that increasing the exhaust flow rate does not reduce risk, in the event of a PRD release, as much as lowering the air conditioning return duct does. This is because the difference in total exhausted gases is small, compared to the volume of the building, during the rather short time span of the PRD release (100 seconds).

Hydrogen burns in air at concentrations between 4.1% and 75%. Whenever hydrogen leaks into air, a burnable mixture of hydrogen and air is formed. The total volume of that burnable cloud determines the severity of an accidental ignition of the cloud. The volume of the burnable cloud is a function of leakage rate and gas motion. This work experimentally determined the severity (overpressure) caused by ignition of these clouds. The work measured the effect of ignition of burnable clouds inside a warehouse of similar volume to that in Sacramento.

The overpressures created by vertical leaks at flow rates up to 38.5 SCFM hydrogen were measured. Measurements were made at distances of 0.46 m (1.5 ft) and 0.91 m (3.0 ft) from the vertical centerline of the leak. The position of the leaks in the warehouse is shown in the schematic in figure A16. The bay was 32.0 m (105.0 ft) in length and 13.7 m (45.0 ft) in width. The exhaust flow rate was sufficient to prevent the accumulation of a burnable mixture of hydrogen and air at the ceiling of the bay. The computer model of the leak shows the size of the burnable mixture of hydrogen (100% LFL) in red. The circulation in the bay can be seen by viewing the green (0.34% LFL) cloud and noting it is tilted toward the exhaust inlet wall. The airflow above the leak is opposite the bulk airflow in the bay. Hydrogen was allowed to leak until a steady state cloud size as viewed in the computer model was formed (300 seconds).

Two frames from a video of the leak (figures A17 and A18) show the flame propagation. Each frame contains two pictures of the flame taken 1/60 second apart. As can be seen in figure A17 during a portion of the first 1/60 second that the flame reaches a height of 0.41 m (1.3 ft). During the following 1/60 second the flame reaches a height of 1.22 m (4.0 ft). As can be seen in figure A18 the flame reaches a maximum height of 1.52 m (5.0 ft) in the third 1/60 of a second. And finally settles into a standing flame during the last 1/60 of a second.

The overpressures measured 0.46 m (1.5 ft) away from the centerline of the flame are shown in figure A19. Maximum overpressure measured at 0.91 m (3.0 ft) away from the centerline of the flame was 0.34 kPa (0.05 psi). The addition of a 2.44 m by 2.44 m (8.0 ft by 8.0 ft) horizontal plywood barrier centered 1.22 m (4.0 ft) above the leak did not measurably alter the data.

The ignition of hydrogen air mixtures trapped under vehicles creates a rapid pressure increase under the vehicle. This is called overpressure, referring to the increase above atmospheric pressure. These have been previously measured for hydrogen air mixtures trapped in a bus wheel well and were found to be less than 1.37 kPa (0.2 psi) for leak rates up to 5 SCFM of pure hydrogen. Those values were substantially lower than the theoretical supplementary predictions because the constraints of fluid dynamics cause most of the hydrogen air mixture to be either too rich or to lean to burn rapidly. This work is to show the possible overpressure created by ignition of hydrogen air mixtures trapped under vehicles. A full-scale model of the front half of a bus was constructed (Figures A20 and A21). It was used to experimentally determined how large and overpressure can be created by hydrogen leaking under the vehicle. Leakage rates up to 13 CFM were tested (Figures A22 and A23). Overpressures never exceeded the 0.21 kPa (0.03 psi) detectability limit of the instrumentation.

Figure A 20 is a picture of the bus model. The fluid dynamics of gas motion under the bus would not have been affected by adding sheet metal to the sides of the bus and was not used as it would have impeded visualization of the bus floor. Figure A 21 is a schematic of the bus.

Dimensions are given in feet. The front half of the bus he was 15. 9 long and 9.8 feet high (not including 0.9 ft. ground clearance) and 7.8 feet wide. The floor of the bus he is 3.3 ft. above the ground. Under the floor of the bus, there are two spaces on either side of the bus for batteries that are 1.1 feet high and 2.65 feet wide and run the full length of the bus. There then remains a tunnel 1.1 feet tall by 2.5 feet wide running the full length of the bus between the battery storage areas.

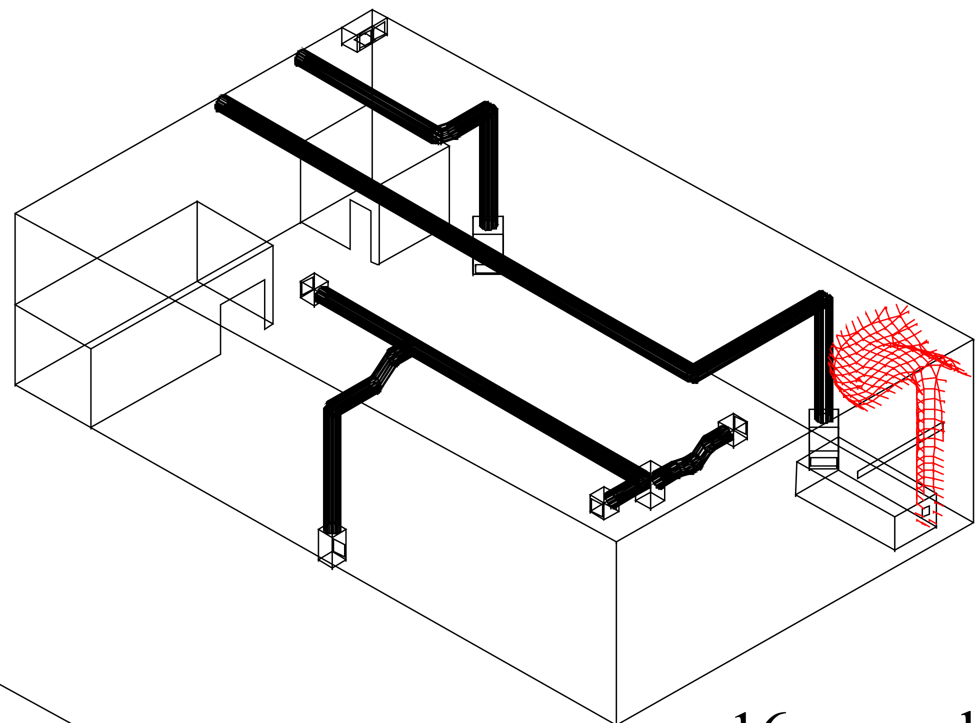
The tunnel was the first volume to fill with hydrogen. The battery storage areas could have been vented to further reduce hydrogen accumulation, but such vents were not used for these tests. Figure A 22 is a computer model of hydrogen leakage into the tunnel. Surfaces of constant hydrogen concentration are displayed in various colors on the figure. The value of hydrogen concentration as indicated by the color. The leak occurred at the left end of the tunnel. Note that there are higher concentrations closer to leak. The tunnel was closed at the left end. Hydrogen could not exit that and of the tunnel unless it was lower than 0.9 ft. from the ground. The hydrogen air mixture was ignited directly above the leak where the gas mixture was in excess of 25% hydrogen. Leaks were ignited after forty minutes of leakage when the flow had stabilized. Figure A 23 shows an ignition of the hydrogen. The leak is seen as a triangular wedge of flame extending up from the leak source.

Conclusions

The answers to the six questions concerning the CaFCP building are as follows:

1. The garage door should not be opened upon detection of hydrogen in bays with a garage door located on the west side of the bay.
2. If a PRD release occurred in close proximity to the air conditioning return duct, the air-conditioning system would fill with a burnable hydrogen air mixture.
3. The vehicle position restrictions necessary to prevent burnable hydrogen air mixtures from entering the air conditioning return duct during a PRD release would prohibit vehicles from occupying over one-half of the bay.
4. The air conditioning return duct should be lowered 2.44 m (8 feet) to reduce the likelihood that a burnable hydrogen air mixture would enter the duct during a PRD release.
5. The maximum recorded overpressures created by a 38.5 SCFM hydrogen leak was 1.16 kPa (0.17 psi) at a distance of 0.46 m (1.5 ft.) from the centerline of the leak.
6. The maximum recorded overpressure created by 13 SCFM hydrogen leak under the full-scale model of the front half of a hydrogen fueled bus was less than 0.21 kPa (0.03 psi).

Exhaust: 2100/6300 SCFM
A/C: 0 SCFM
H_2 Leak: 80 SCFM
Red – 4.1%
Blue – 0.82%



16 seconds

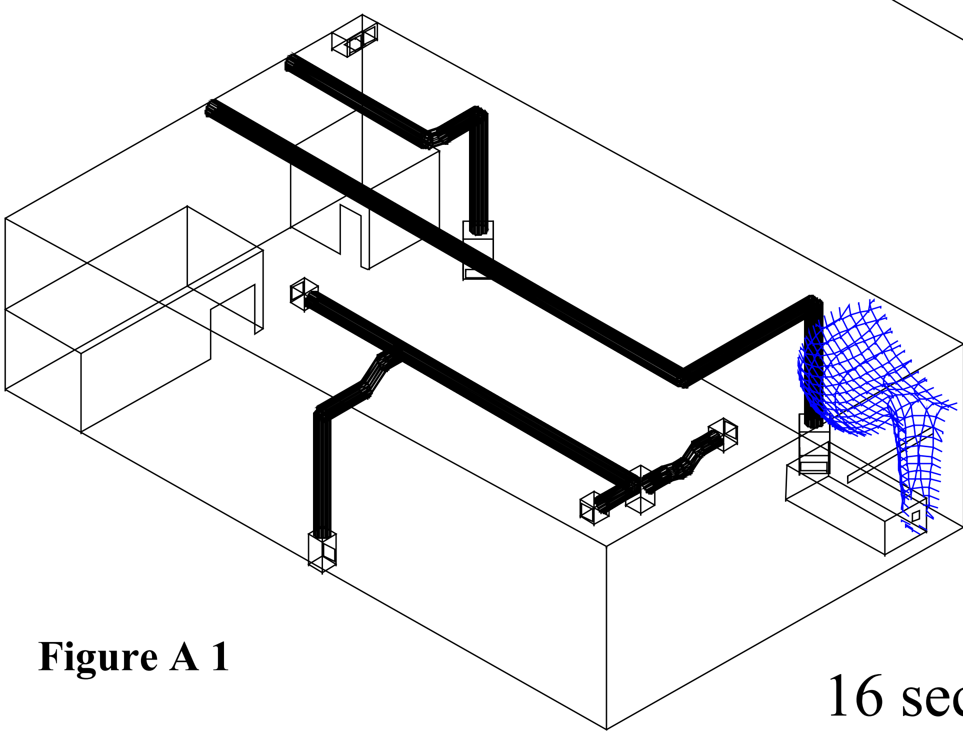
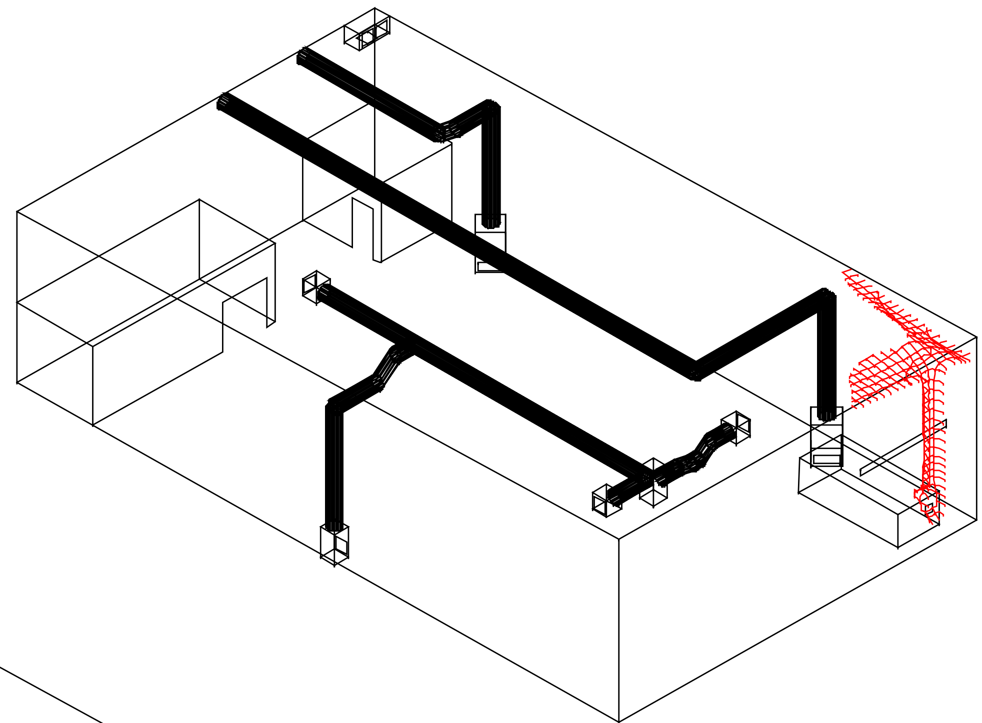


Figure A 1

16 seconds

Exhaust: 2100/6300 SCFM
A/C: 0 SCFM
H_2 Leak: 80 SCFM
Red – 4.1%
Blue – 0.82%



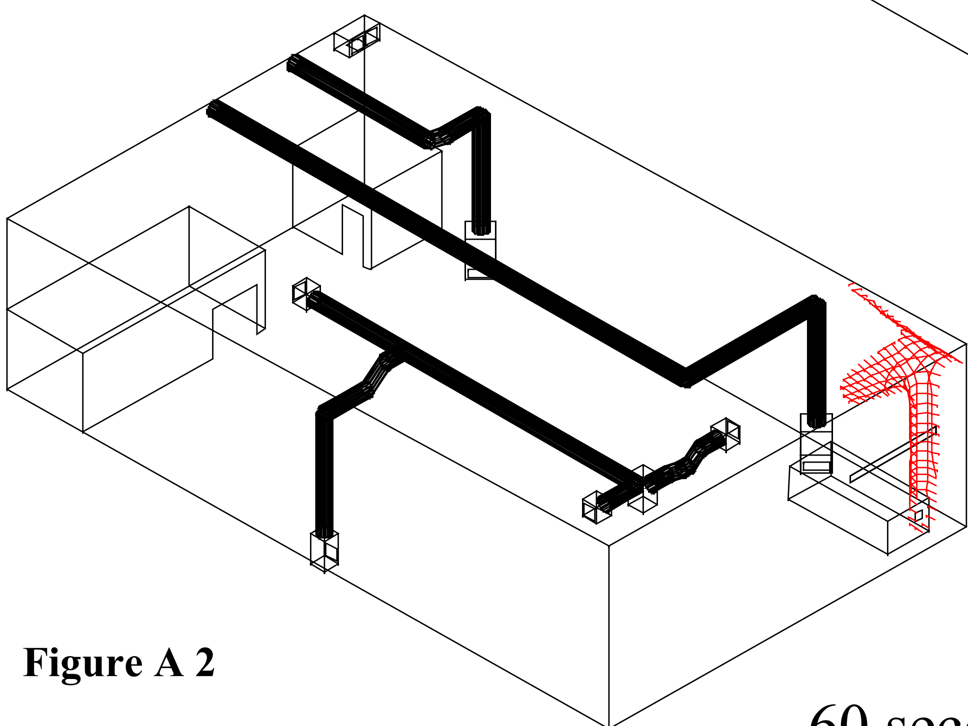
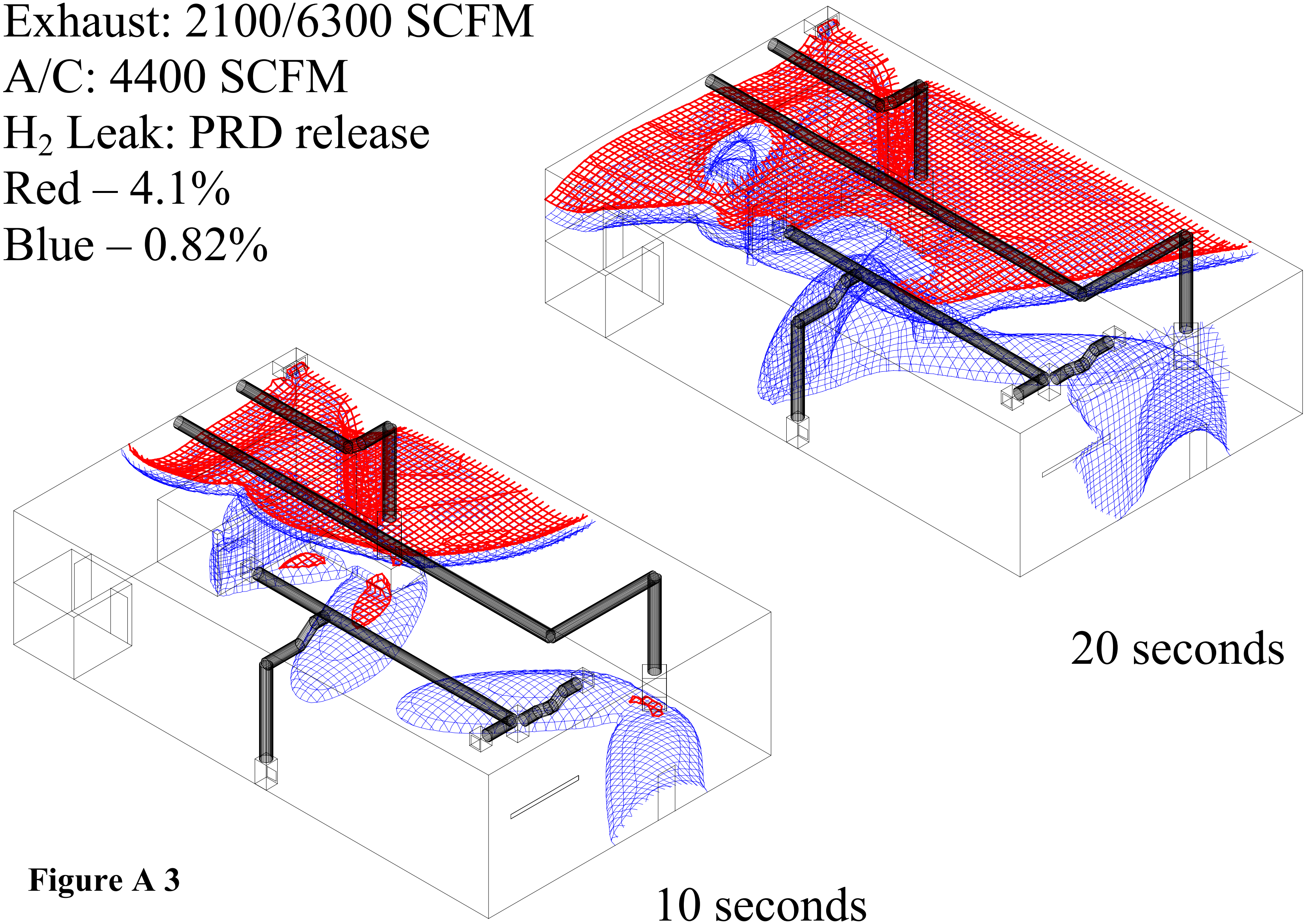


Figure A 2

Exhaust: 2100/6300 SCFM
A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 4.1%
Blue – 0.82%

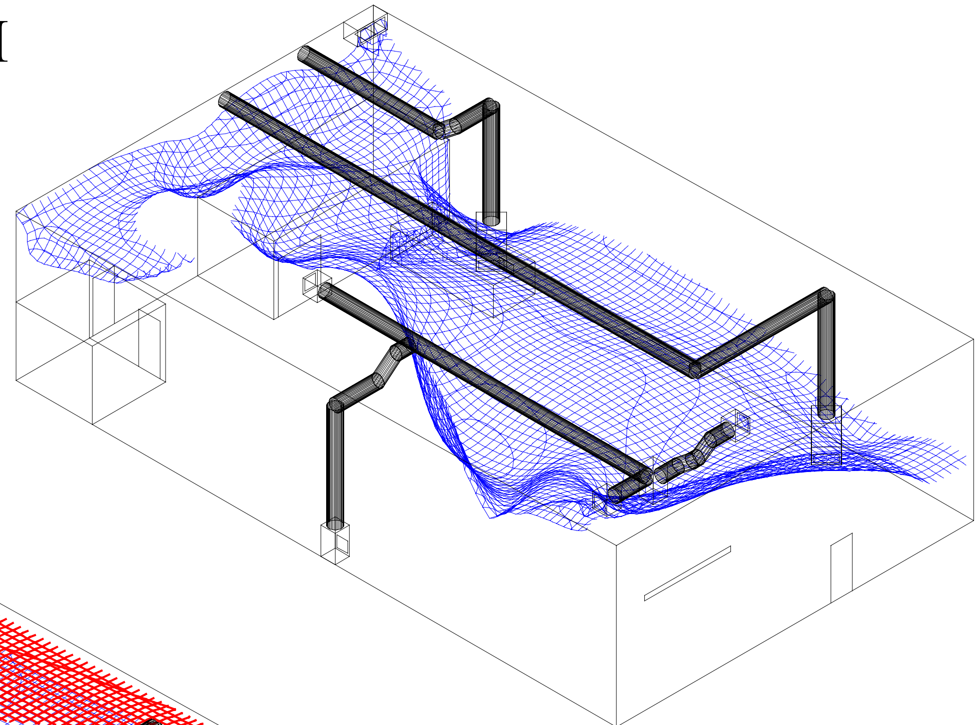


20 seconds

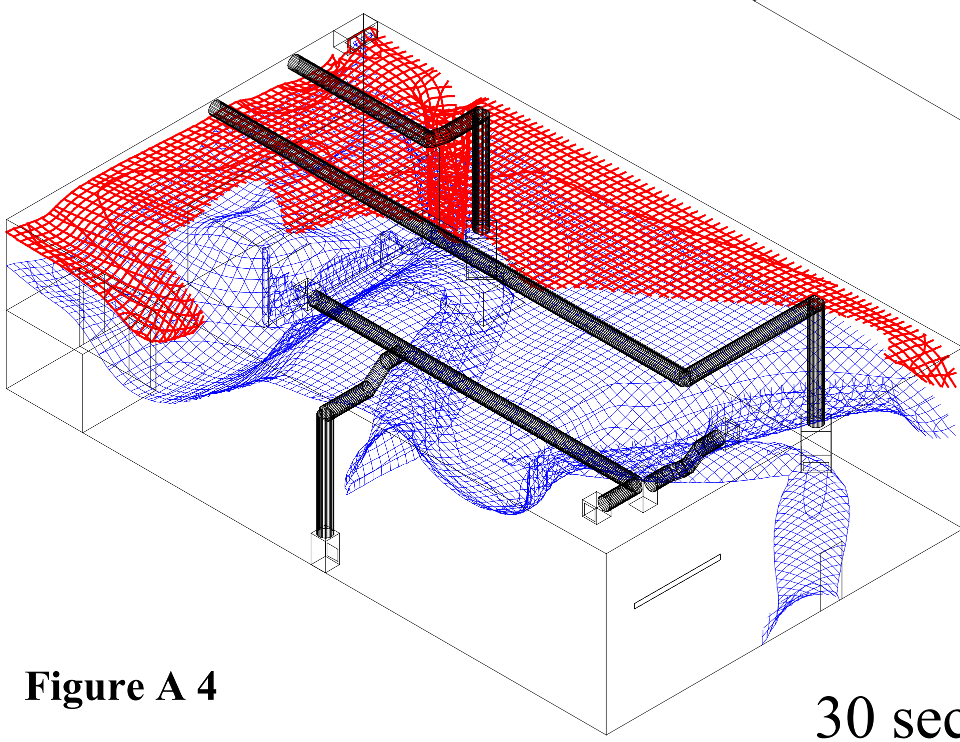
10 seconds

Figure A 3

Exhaust: 2100/6300 SCFM
A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 4.1%
Blue – 0.82%



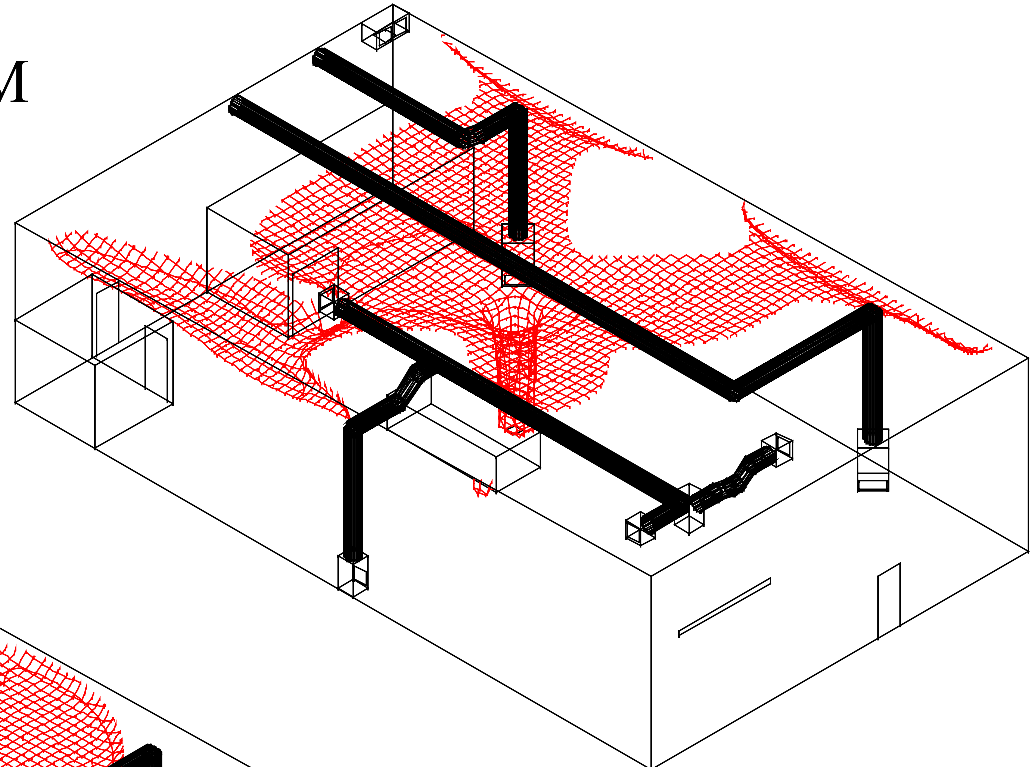
100 seconds



30 seconds

Figure A 4

Exhaust: 2100/6300 SCFM
A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 4.1%
Blue – 0.82%



20 seconds

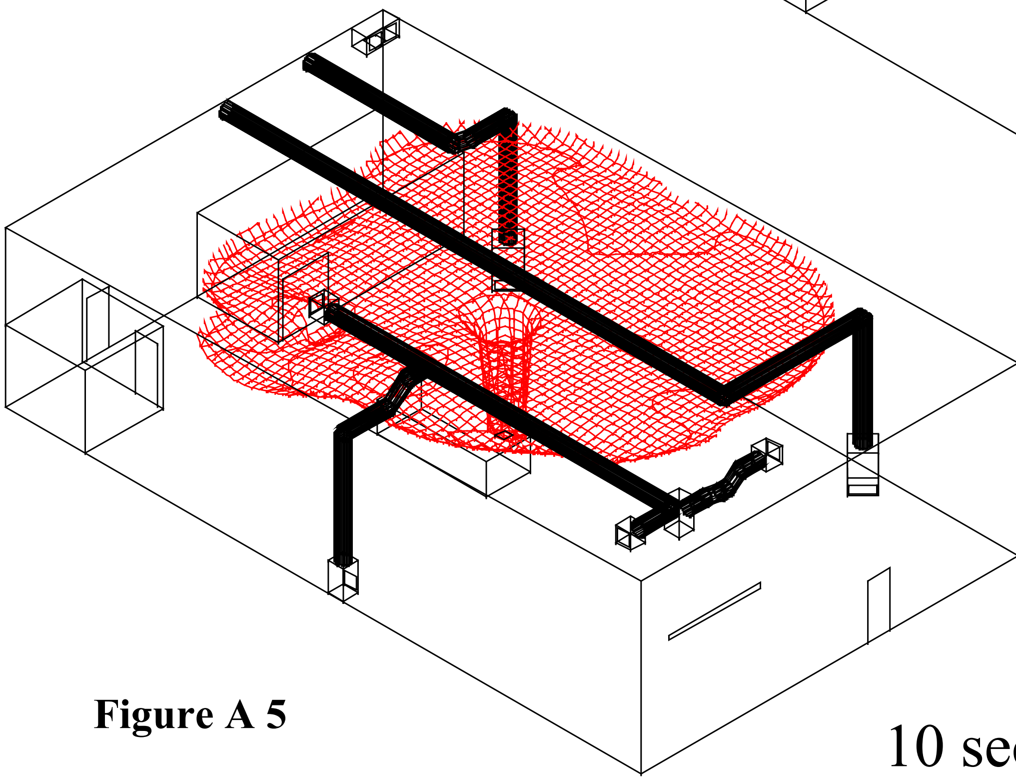
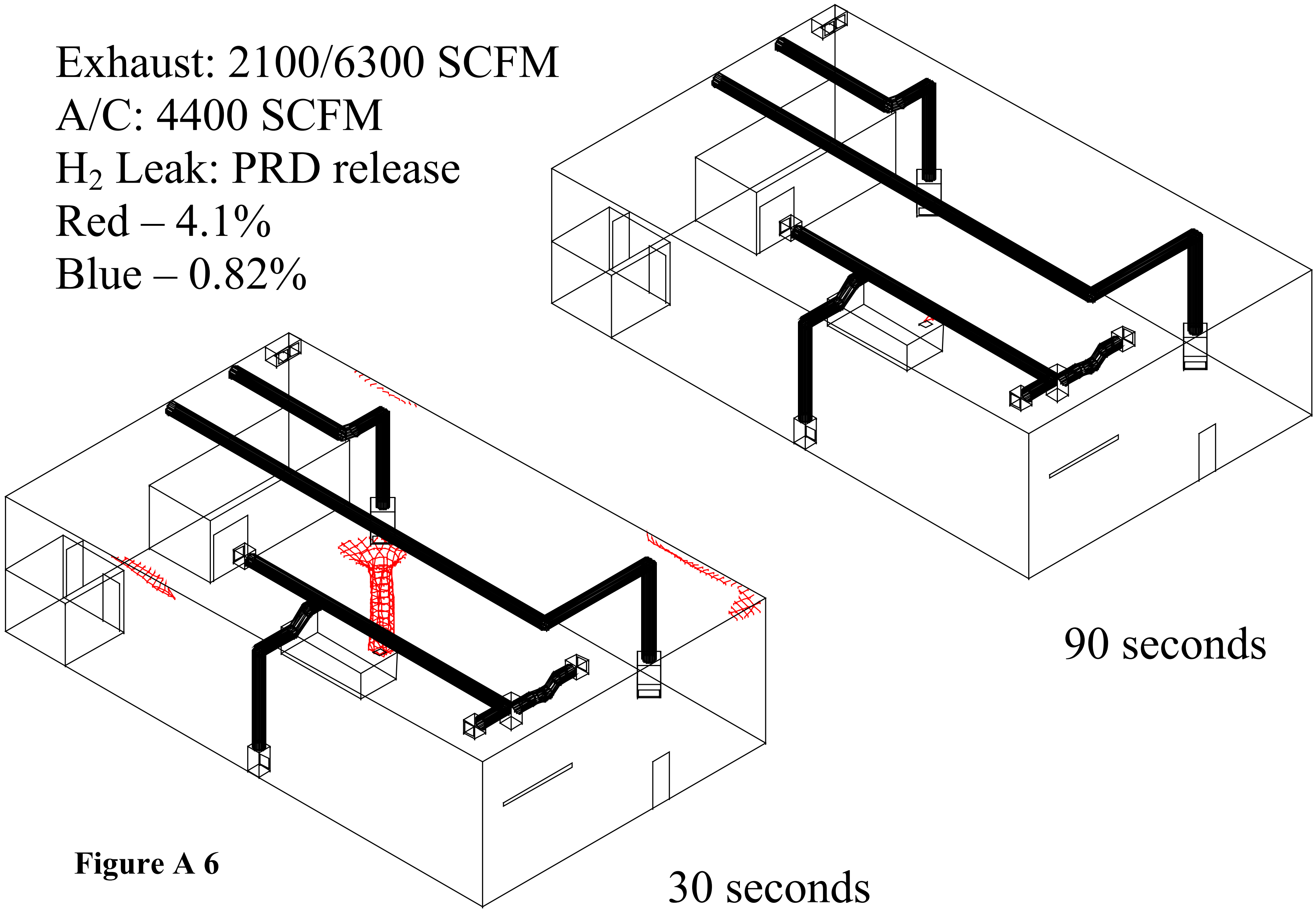


Figure A 5

10 seconds

Exhaust: 2100/6300 SCFM
A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 4.1%
Blue – 0.82%

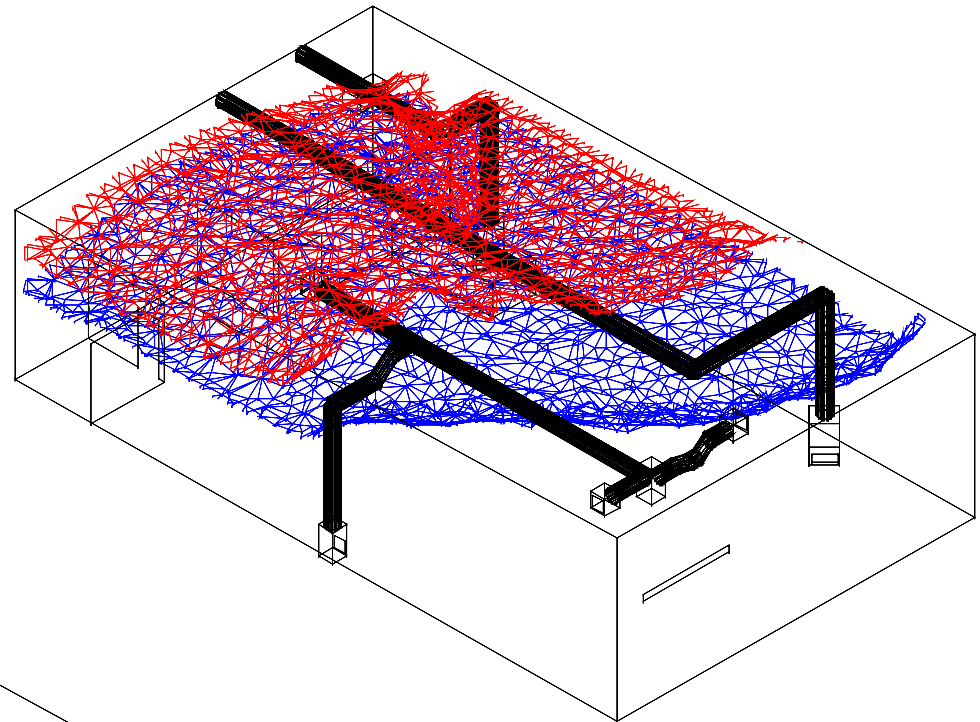


90 seconds

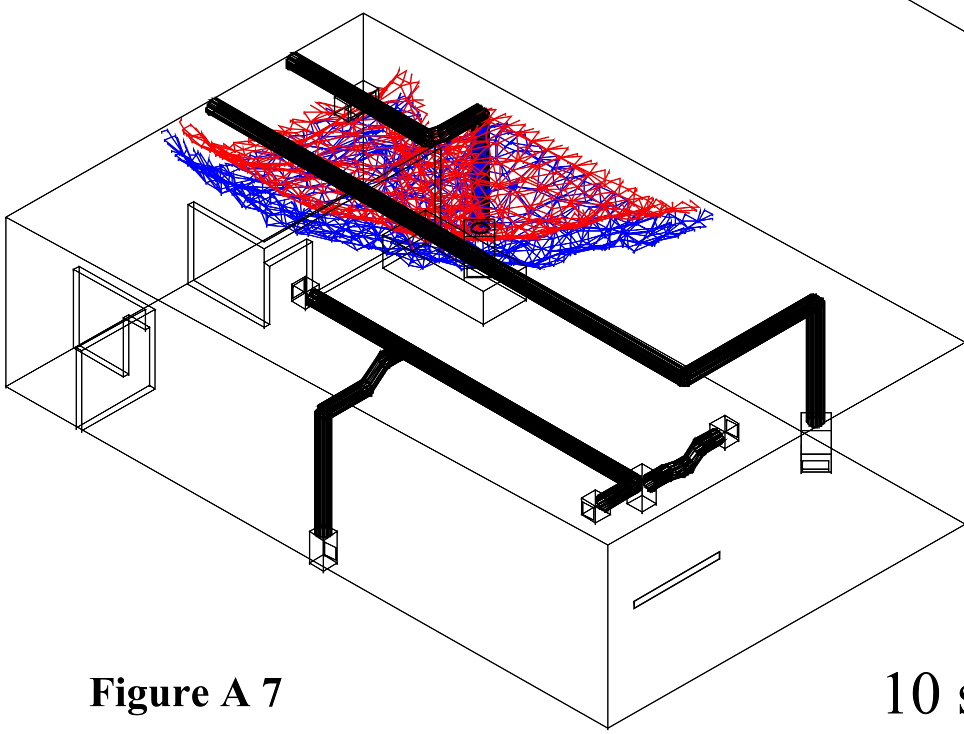
30 seconds

Figure A 6

Exhaust: 2100/6300 SCFM
A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 4.1%
Blue – 0.82%



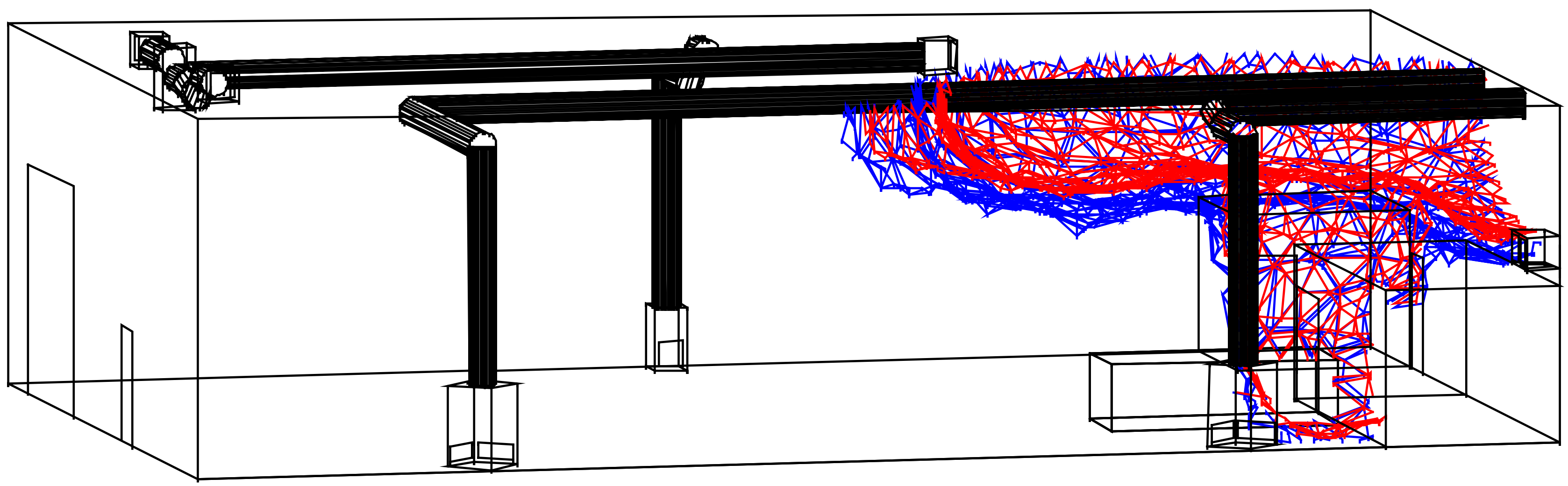
30 seconds



10 seconds

Figure A 7

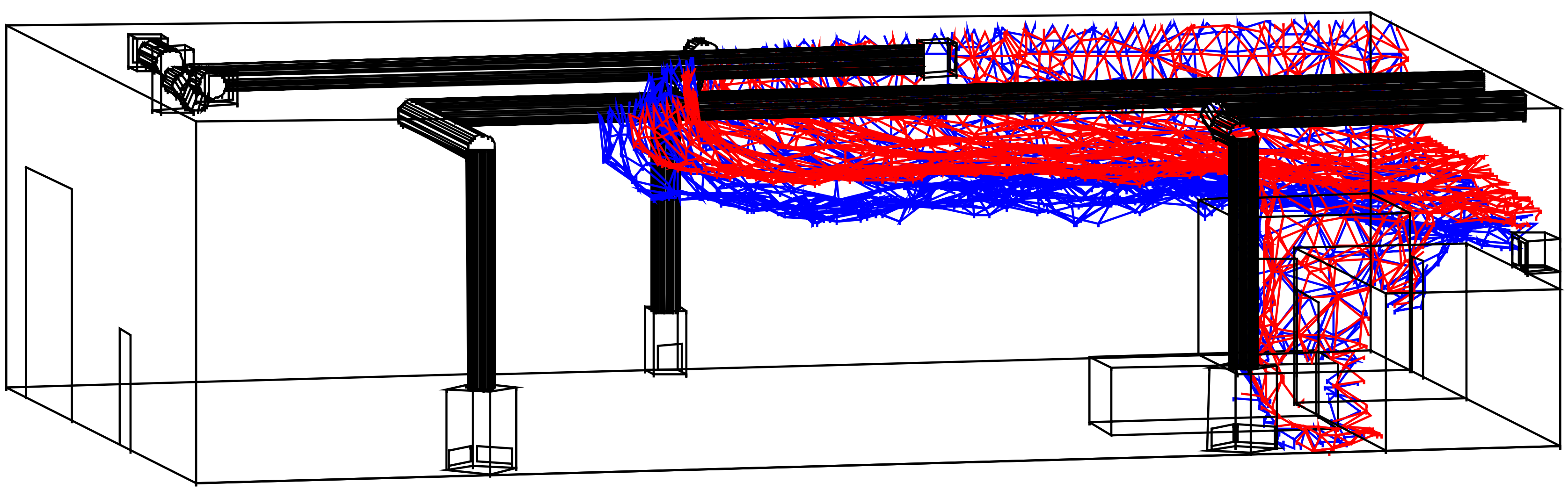
Exhaust: 2100/6300 SCFM
A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 4.1%
Blue – 1.0%



5 seconds

Figure A 8

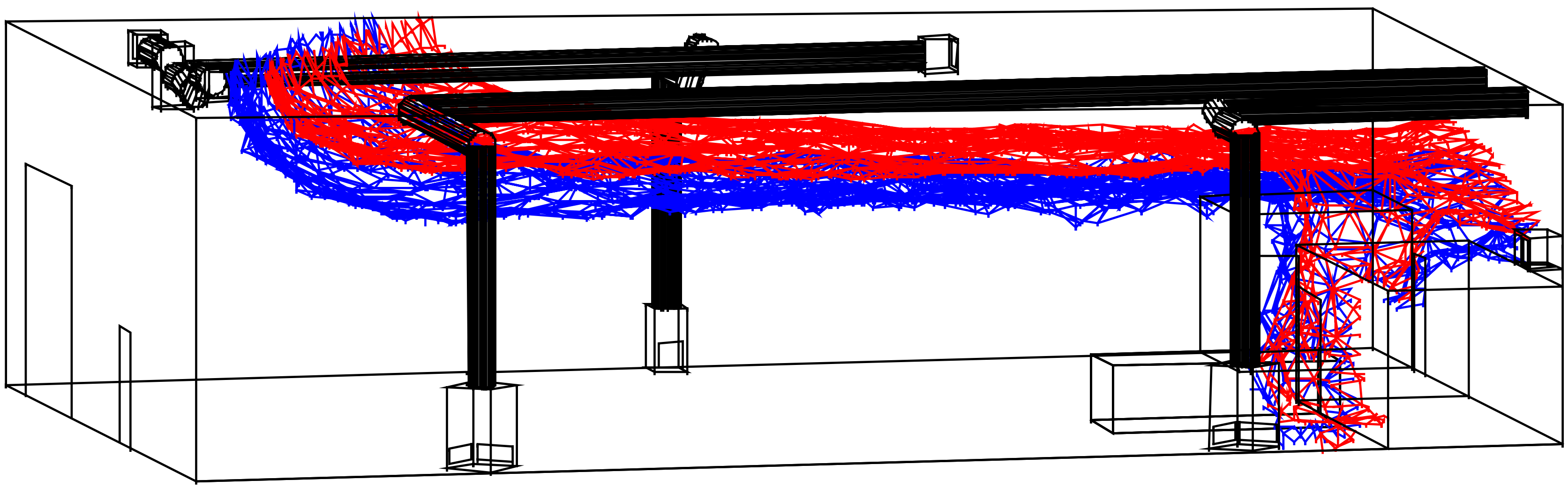
Exhaust: 2100/6300 SCFM
A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 4.1%
Blue – 1.0%



10 seconds

Figure A 9

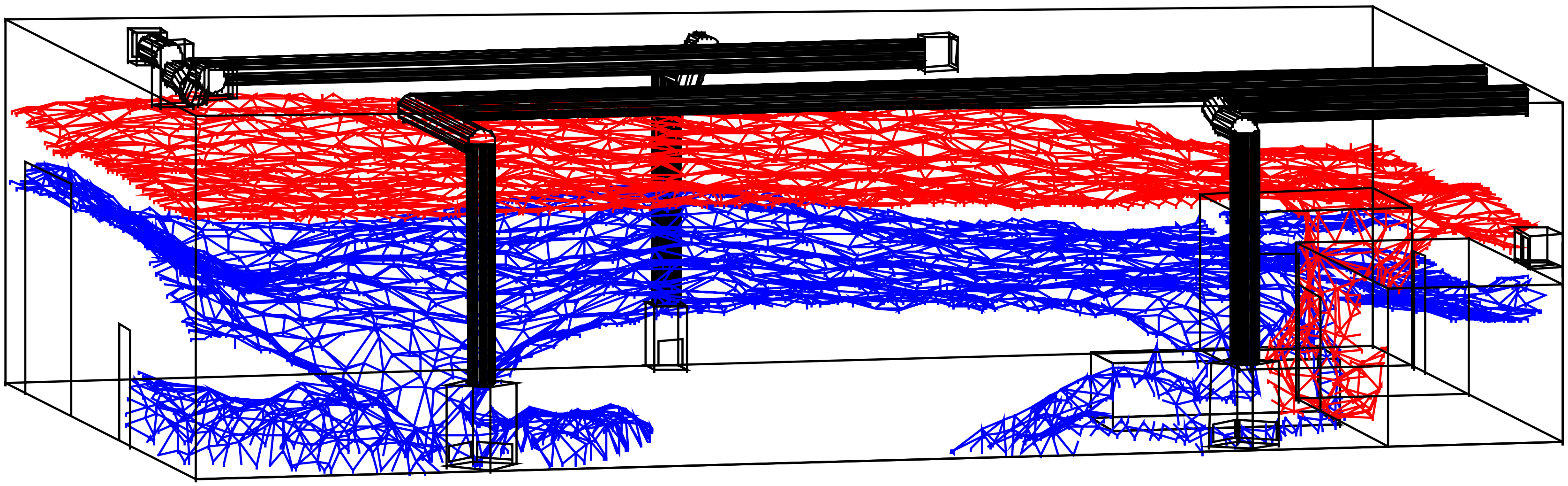
Exhaust: 2100/6300 SCFM
A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 4.1%
Blue – 1.0%



20 seconds

Figure A 10

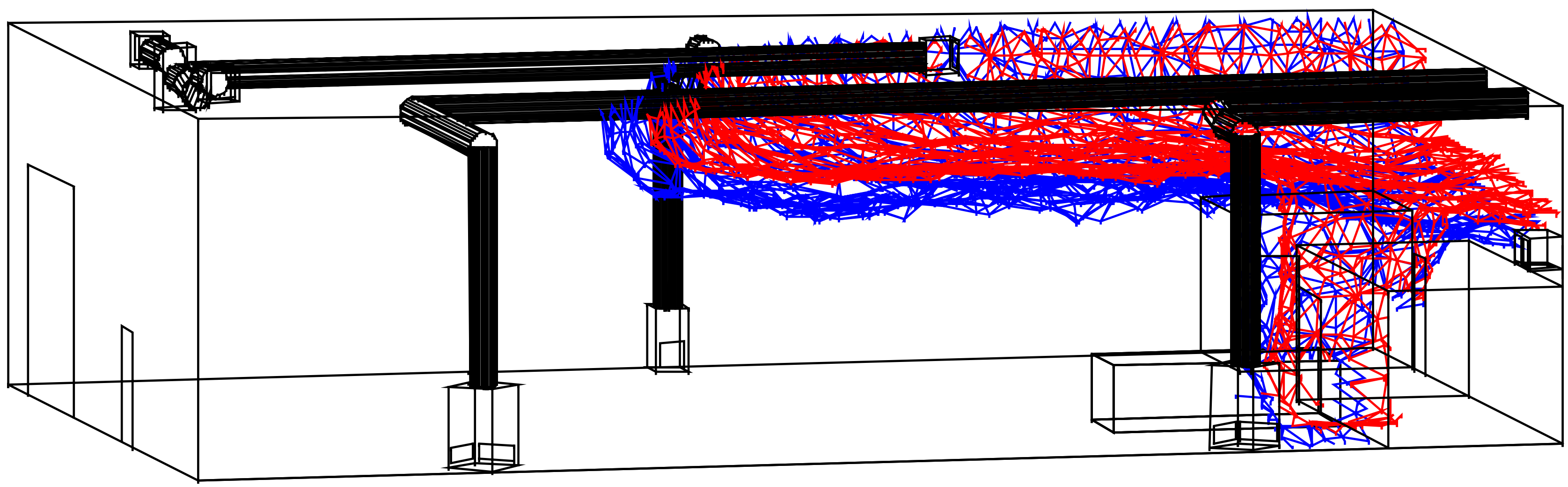
Exhaust: 2100/6300 SCFM
A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 4.1%
Blue – 1.0%



80 seconds

Figure A 11

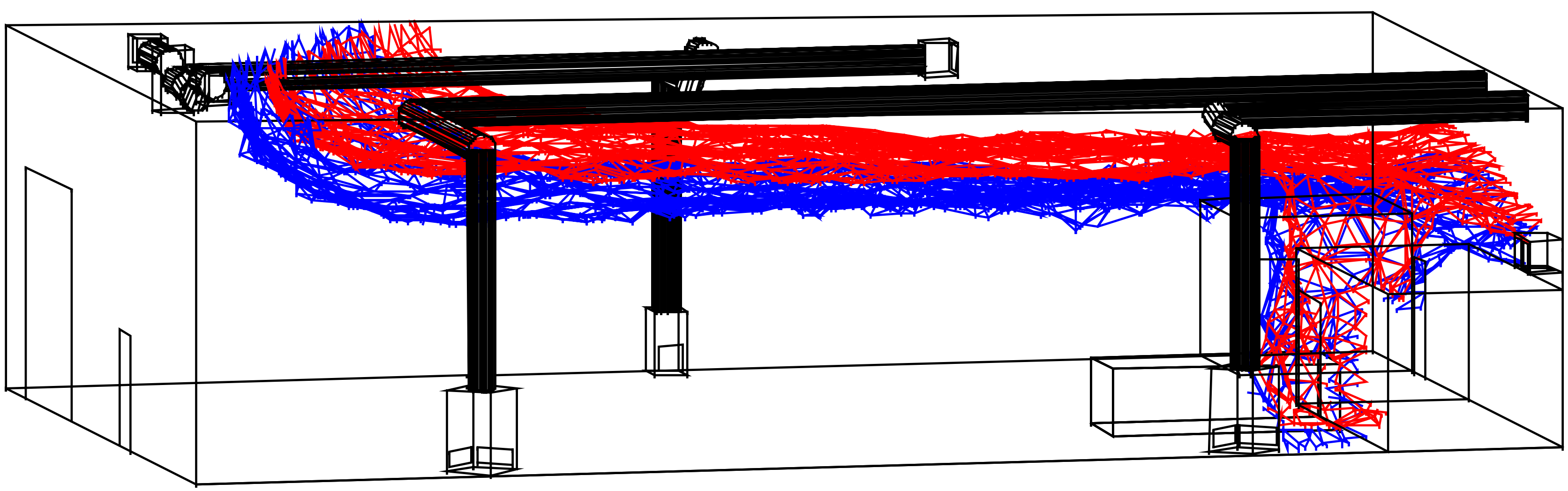
Exhaust: 2100 SCFM
A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 4.1%
Blue – 1.0%



10 seconds

Figure A 12

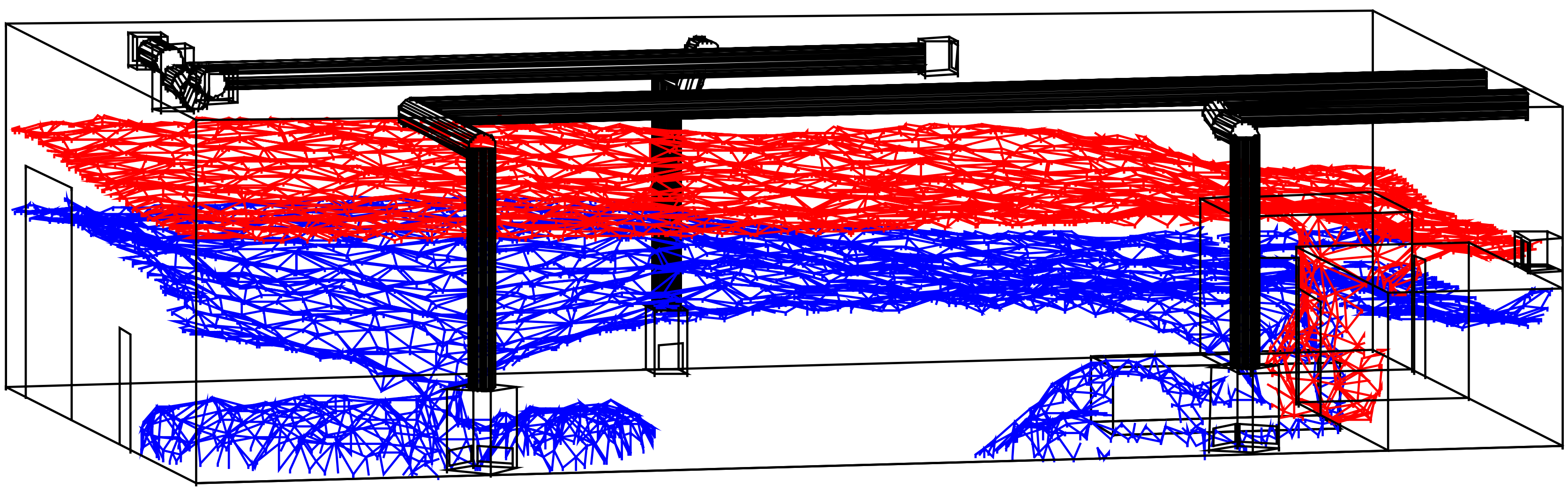
Exhaust: 2100 SCFM
A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 4.1%
Blue – 1.0%



20 seconds

Figure A 13

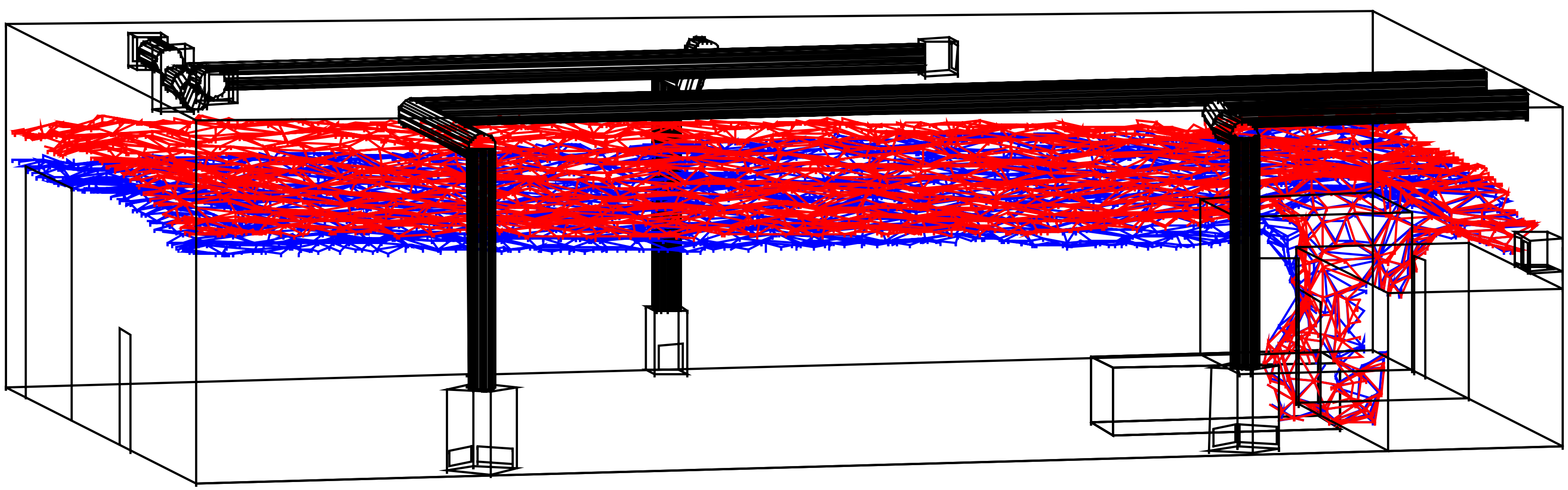
Exhaust: 2100 SCFM
A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 4.1%
Blue – 1.0%



80 seconds

Figure A 14

A/C: 4400 SCFM
H_2 Leak: PRD release
Red – 6300 SCFM Exhaust
Blue – 2100 SCFM Exhaust
4.1% hydrogen concentration



100 seconds

Figure A 15

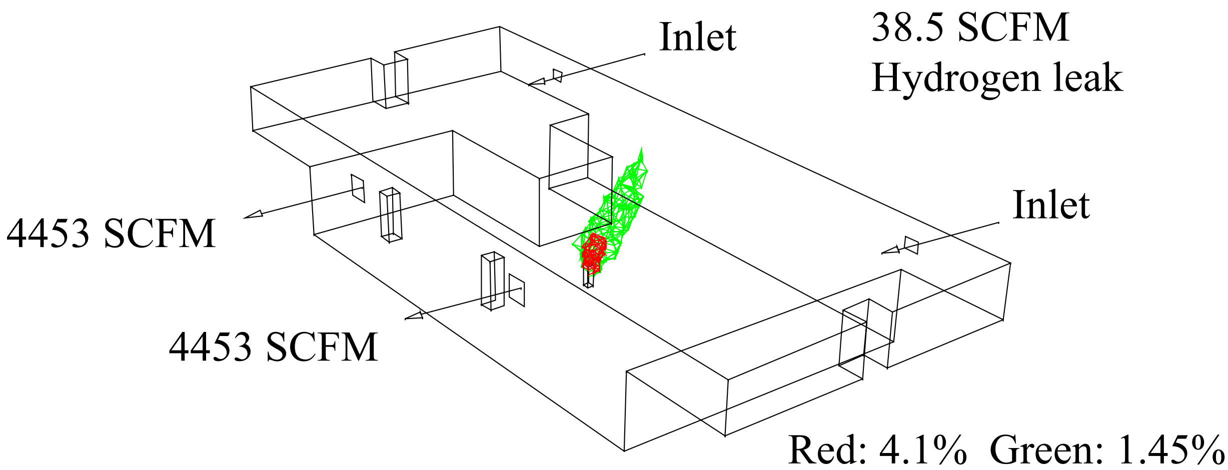


Figure A 16 – Schematic of warehouse

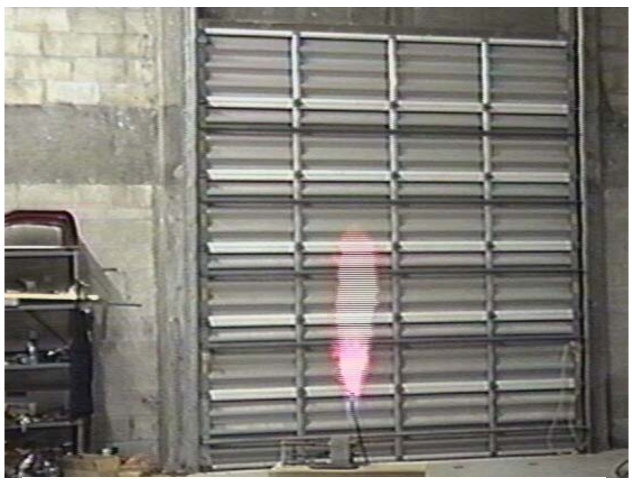


Figure A 17 - First frame from video

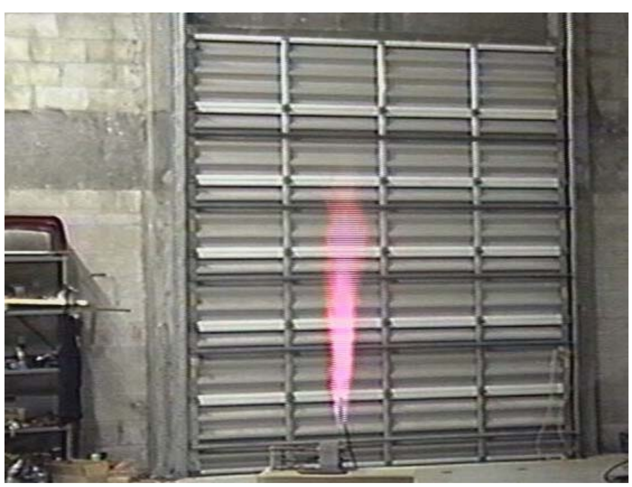


Figure A 18 – Second frame from video

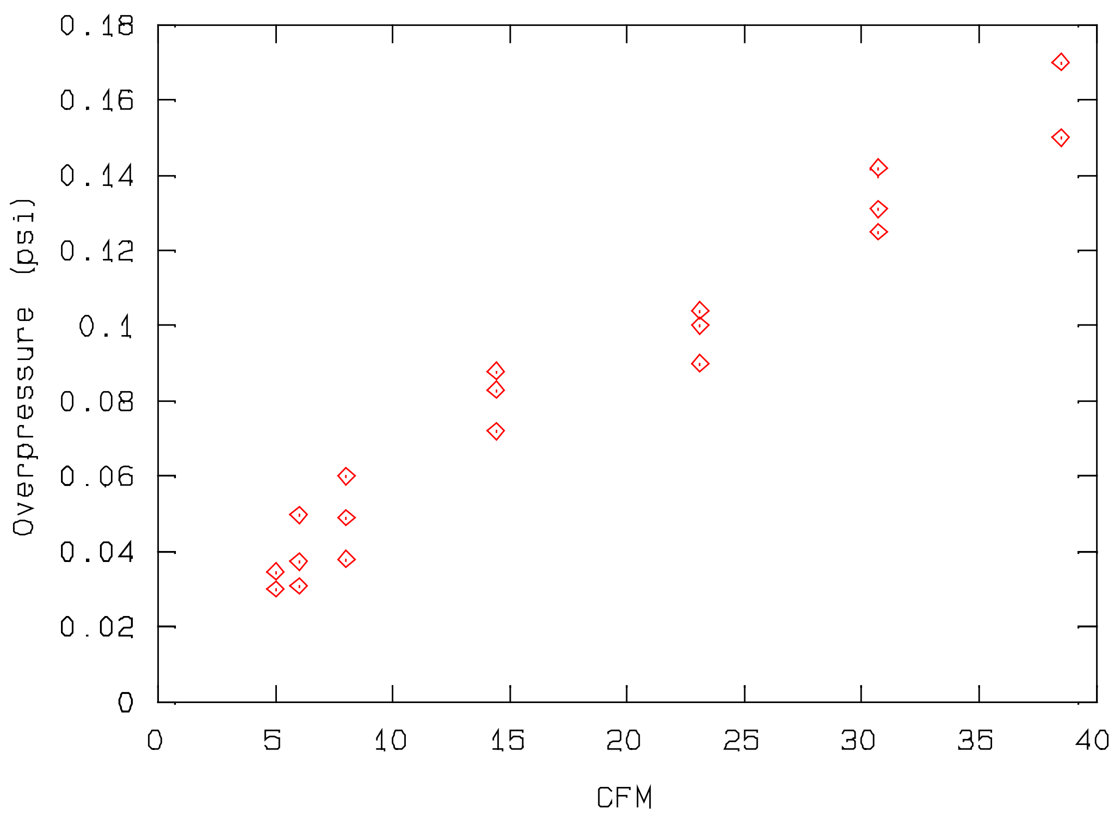


Figure A 19 – Measured overpressures versus hydrogen leak flow rate

Figure A 20 – Full scale model of front half of bus

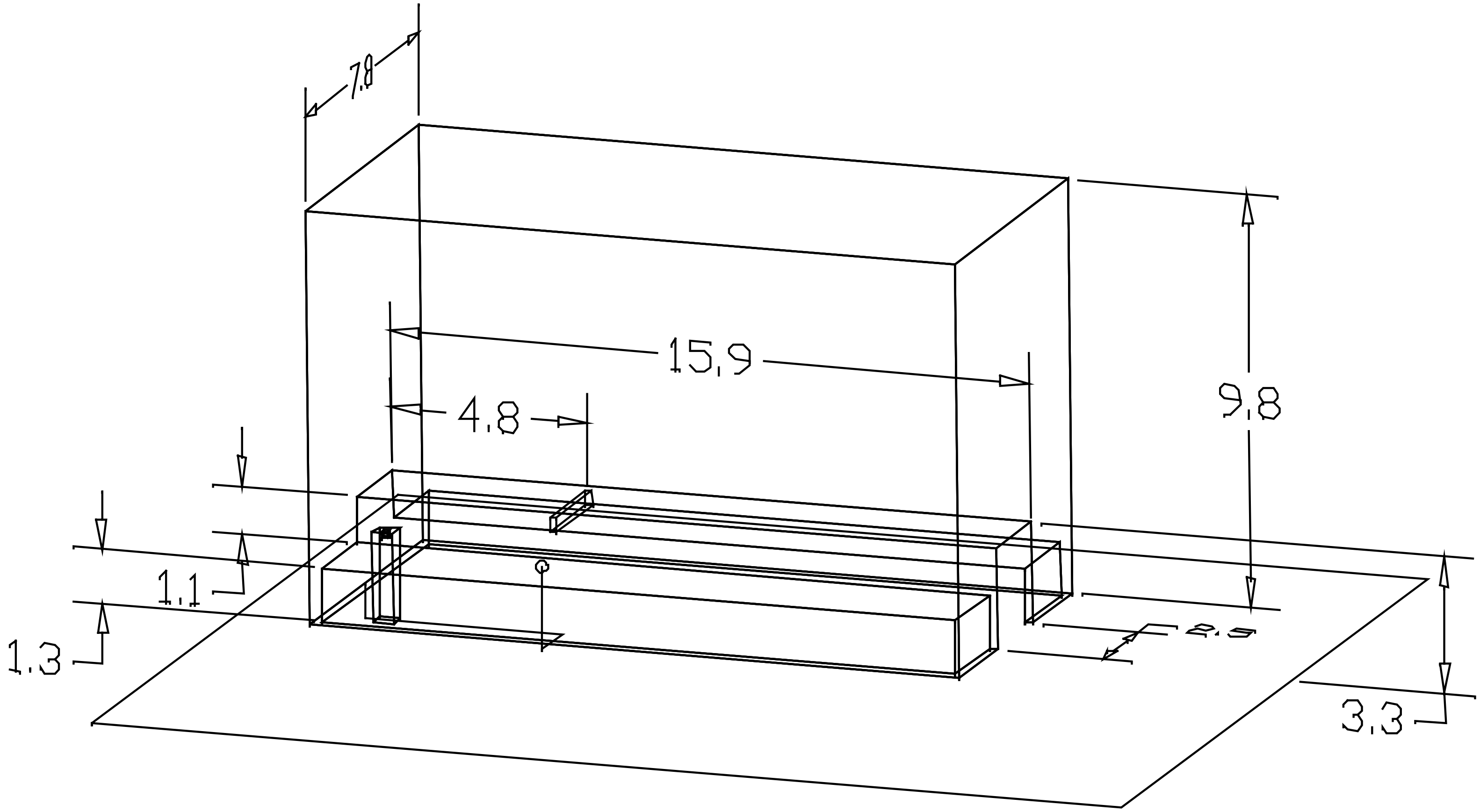


Figure A 21 – Schematic of model of full scale bus

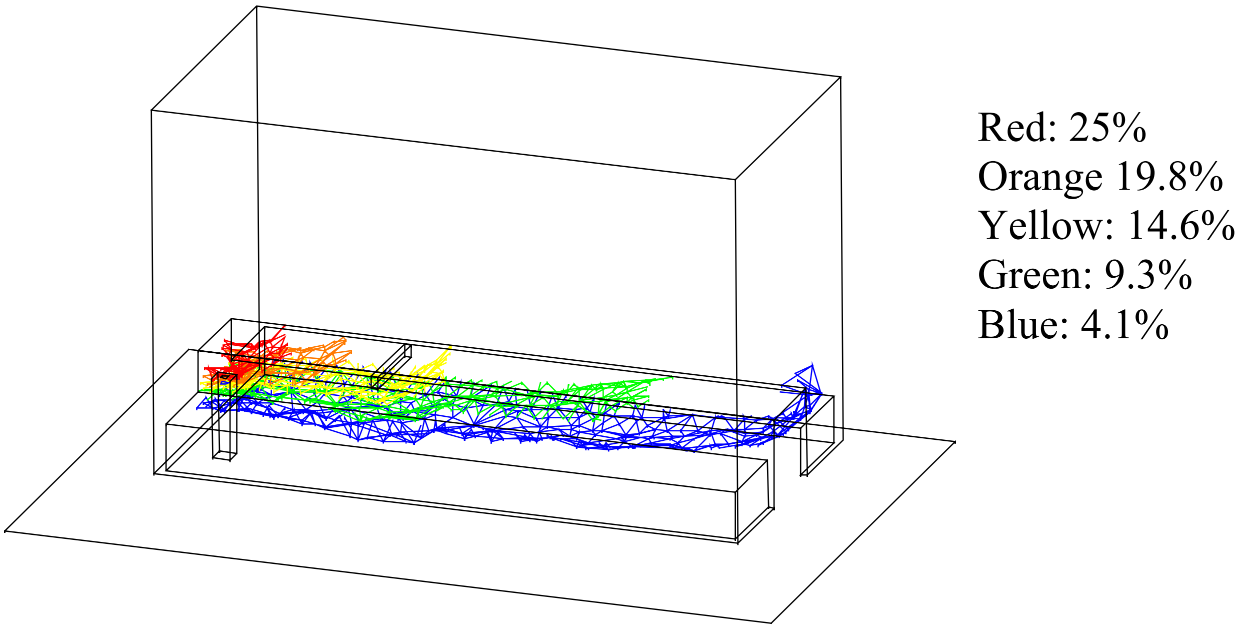


Figure A 22 – Computer model of 13 SCFM hydrogen leak under bus after 2400 seconds

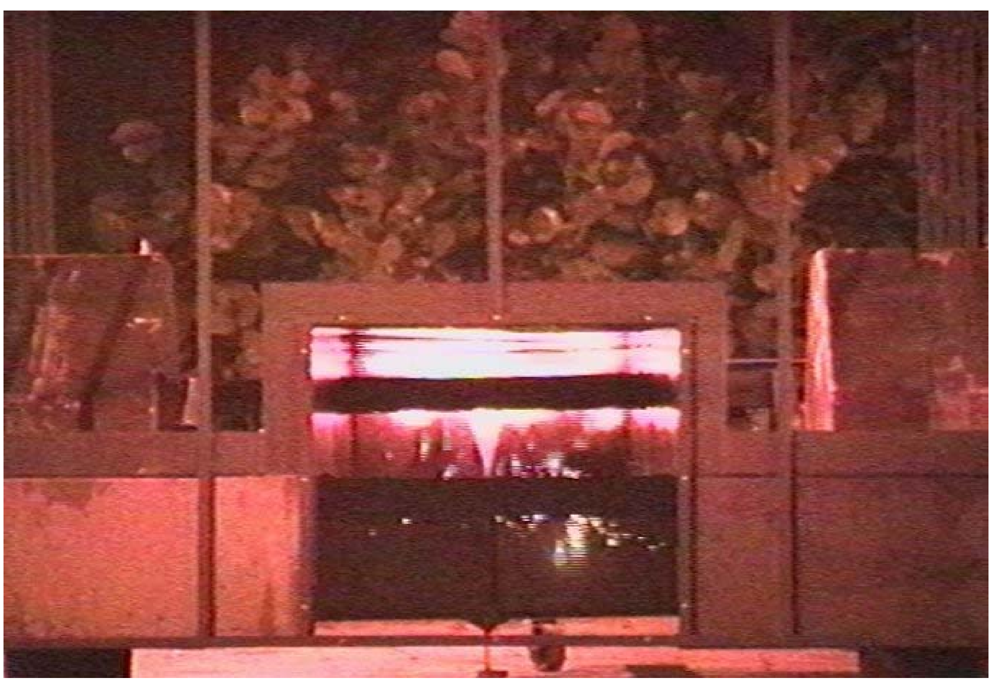


Figure A 23 – Ignition of 13 SCFM hydrogen leak under bus

Task B – Development of Method to Determine Hydrogen Sensor Placement

This work was done to develop a simple method to visualize the motion of gases from a hydrogen leak. Visualizing the motion of the leaking gases is needed to determine optimized hydrogen sensor locations for safety applications.

The motion of the leaking gases was visualized using helium filled soap bubbles. Initially, helium filled bubble clusters were studied. The bubble clusters could be generated at near neutral buoyancy, which allowed low velocity air motion to be visualized quite easily. However, the bubble clusters tended to exhibit variable density as the soap bubble solution dripped from the bottom of the cluster or bubbles at the top of the cluster burst. This produced erratic behavior, and the soap bubble clusters would rise and fall as the density would drop and rise.

Single bubbles produced much more predictable behavior. Bubble solution rarely dripped from a single bubble though they did eventually burst. Single bubbles rose more rapidly than bubble clusters, as their overall density was lower. Single bubbles were still of a high enough density to rise more slowly than gases from a hydrogen leak. Rising more slowly than leak gases causes the bubbles to track a conservative path that tends to indicate the furthest extent that leak gases will track away from vertical due to air motion in the room. This allowed good visualization of the gas motion track and indicated target locations high in the room that would be good for hydrogen sensor locations.

A machine was developed that utilized a small diffuser nozzle to generate helium filled bubbles. The machine produces multiple bubbles over time to allow the gas motion to be tracked.

Though a complete write-up is not available at this time, a picture of the device is shown at right.

Figure B 1 – Helium bubble machine

Task C –Safety and Analysis for Writing of Codes

Task C required membership on the International Code Counsel (ICC) Ad Hoc Committee to assist in the writing of codes for the use of hydrogen. The travel consisted of trips to golden, Colorado (June 4th and 5th, 2001); Houston, Texas (October 2nd and 3rd, 2001); Greensboro, North Carolina (October 31st, 2001); Pittsburgh, Pennsylvania (April 18th and 19th, 2002) and eventually Fort Worth, Texas (Sept. 30th to October 4th, 2002). The trips were to attend meetings of the committee and present the results of this work.

Review work was done in cooperation with the Society of Automotive Engineers (SAE) to coordinate SAE J2578 and SAE J2579 with the ICC Ad Hoc committee efforts.

Additionally, work was done in cooperation with the National Fire Protection Association (NFPA) as an appointed member of the Vehicular Alternative Fuel Systems committee.

Hydrogen Flame Impingement

The use of hydrogen fuel vehicles inside wood frame structures may result in hydrogen flame impingement on interior walls. The gypsum board that covers the wood frame can be installed in a variety of ways dependent on code requirements. Tests were run to determine the amount of damage done by hydrogen flame impingement on gypsum board mounted on two by four wood frames. The test utilized 0.77 kg (1.7 lbs) of hydrogen vented in 100 seconds beginning at a flow rate of 1000 SCFM. The jet was placed 0.76 m (2.5 ft) away from the gypsum board as this distance was found to produce the maximum heat transfer in previous tests. Five tests were performed (See Table C1). Figure C1 – C3 show photos of the testing.

Additionally, large-scale gypsum board flame impingement tests were conducted. A gypsum board/two by four stud enclosure was constructed. The enclosure was 4.85 m (15.9 ft.) long, 2.39 m (7.8 ft.) wide and 3.0 m (9.8 ft.) tall (see figure C4). The enclosure was constructed on wheels to make it mobile. The enclosure utilized 5/8 inch Fire Code Type X gypsum board on the ceiling and 1/2 inch gypsum board on the walls. 1.73 kg (3.8 lbs) of hydrogen was released with instantaneous ignition. The purpose of the test was to see if the temperature rise due to the hydrogen flame impinging on the gypsum board in the enclosure was less than the temperature rise of previous tests outside of an enclosure. Because oxygen inside the enclosure was limited, the temperature rise in the enclosure was less than temperature rise outside the enclosure.

Table C -- 1

Gypsum board thickness	Distance between two by fours	Maximum temperature rise at back of gypsum board
1/2 inch sheet	Twenty-four inches	80.0 ºC. (144 ºF)
1/2 inch sheet	Sixteen inches	78.9 ºC. (142 ºF)
5/8 inch sheet	Twenty-four inches	70.0 ºC (126 ºF)
Two 5/8 inch sheets	Twenty-four inches	2.2 ºC (4 ºF)
5/8 inch sheet with seam	Twenty-four inches	76.7 ºC (138 ºF)
5/8 inch sheet enclosed	Sixteen inches	54.4 ºC (98 ºF)

It can be seen that the use of two 5/8 inch sheets of Fire Code Type X gypsum board reduced heat transfer through the boards to nearly zero. This same test conducted with automobile door sheet metal produces a temperature rise on the order of 777.8 ºC (1400 ºF).

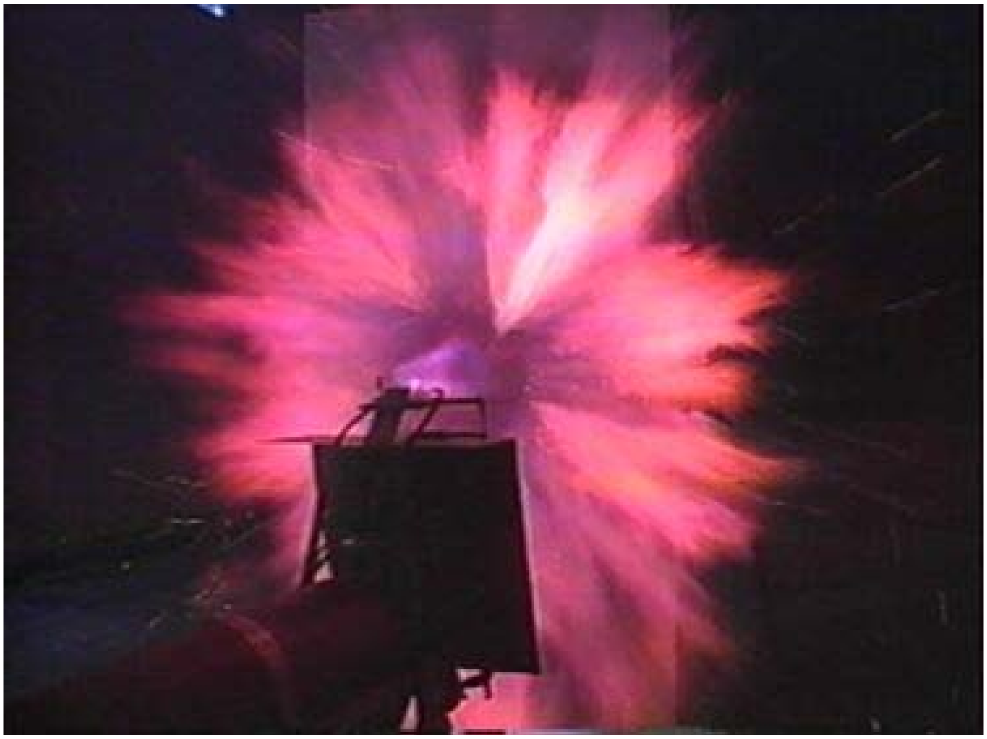


Figure C 1 – Hydrogen flame impingement on gypsum wallboard seam

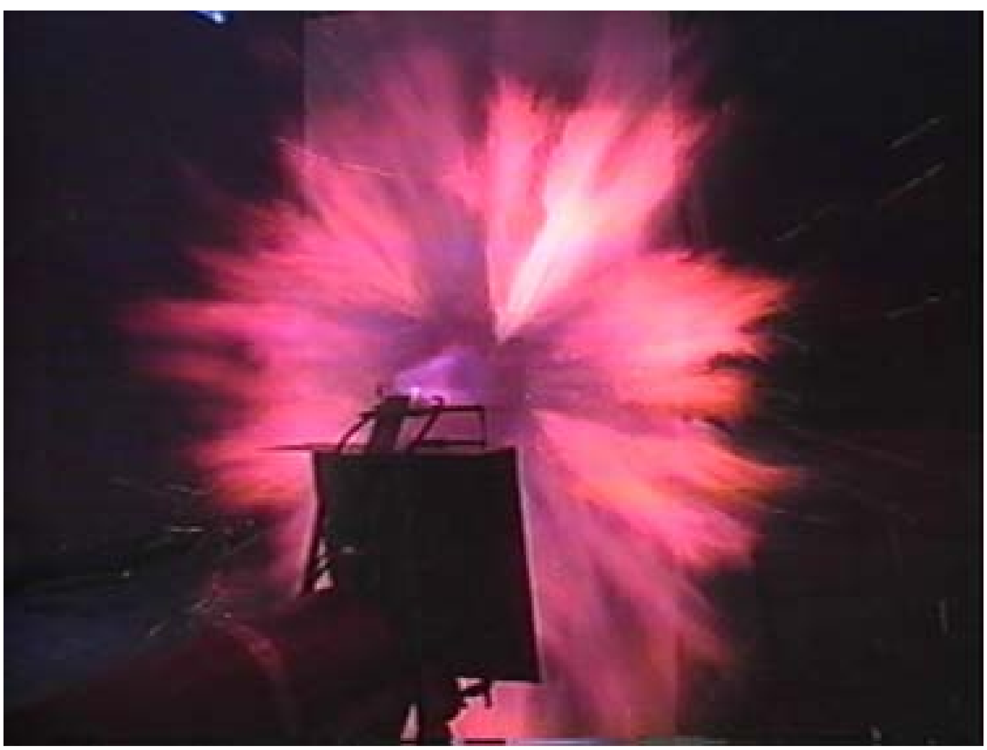


Figure C 2 – Hydrogen flame impingement, early in burn

Figure C 3 – Hydrogen flame impingement on gypsum wallboard (paper cover burning)

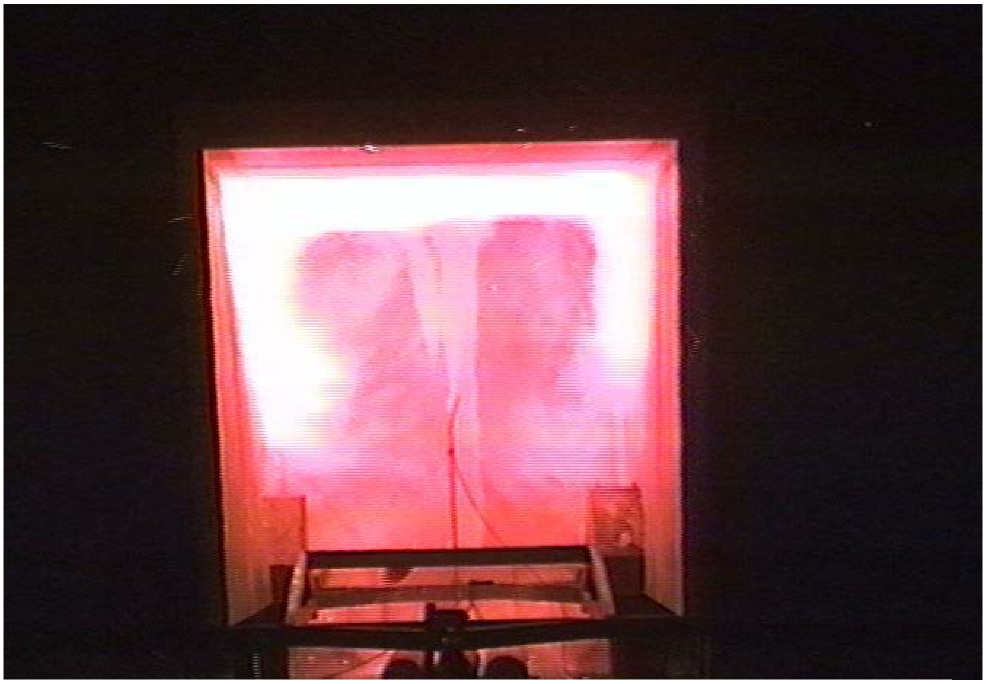


Figure C 4 - Large scale gypsum board flame impingement test

Computer Modeling of Two-Car Garage

Computer analysis was conducted to show the effects of increasing garage size, from single car to double car. The modeling was done specifying an upper vent size of 0.5 sq. ft. per 1000 cubic feet of garage volume. The larger garage size requires that the leaking hydrogen must travel further before exiting the garage. While this tends to make hydrogen removal more difficult, the fact that the vent size is doubled due to the increased garage volume and the volume of air in the garage was also doubled tends to reduce the hydrogen concentration in the garage. The effect can be seen in figures C5-C8. Figure C5 shows the effect of 20 minutes of hydrogen leakage in a single car garage without vents. The burnable letter of hydrogen at the ceiling his 34 inches thick and will continue to grow with time. Figure C6 shows the effect of 20 minutes leakage in a single car garage with vents. The burnable layer is reduced to 11 inches and has reached essentially steady-state. Figure C7 shows the effect of 20 minutes leakage in a double car garage with vents. The burnable hydrogen gasses are confined to a narrow column above the leak. Note that the leak was placed as far from the vents as possible and the vents were not centered in the wall but rather placed near the end of the wall away from the leak. The hydrogen cloud had not reached steady-state in 20 minutes. Figure C8 shows the steady-state cloud at fifty-three minutes.

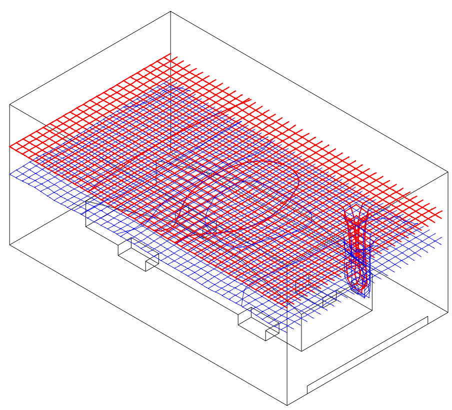


Figure C 6 - Unvented 1 car garage, 4 SCFM hydrogen leak for 20 minutes. Blue: 0.82% hydrogen. Red: 4.1% hydrogen

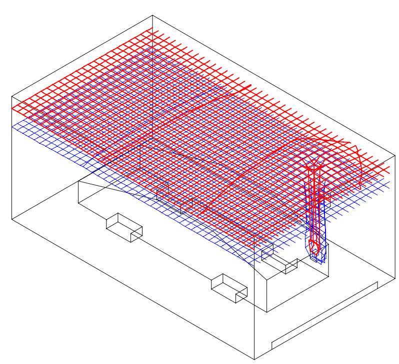


Figure C 5 - Vented 1 car garage, 4 SCFM hydrogen leak for 20 minutes. Blue: 0.82% hydrogen. Red: 4.1% hydrogen

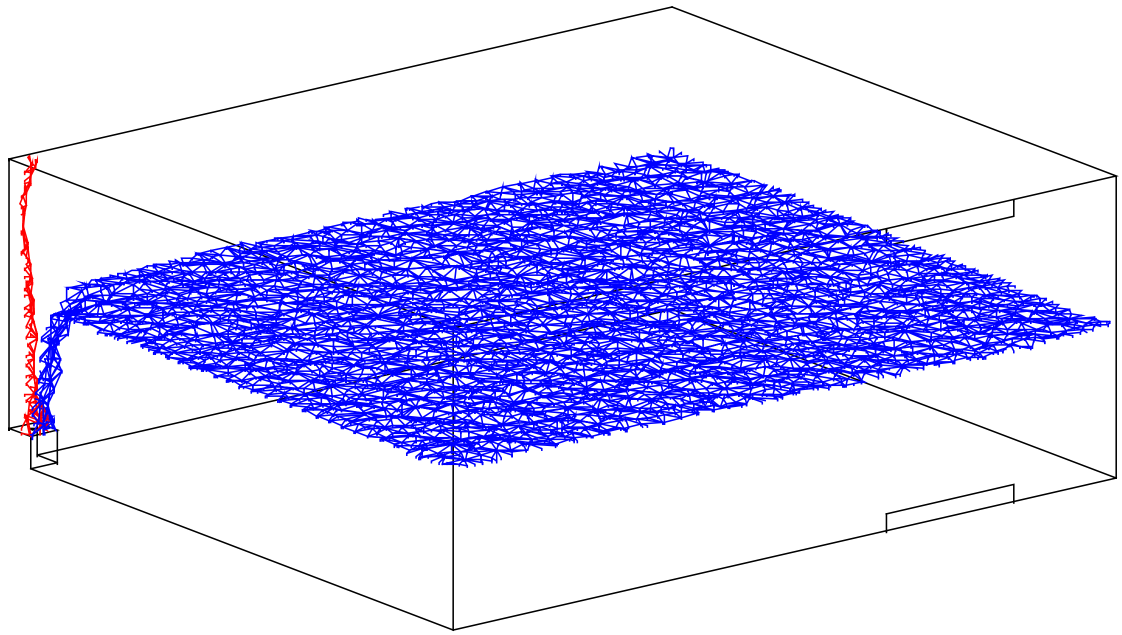


Figure C 7 - Vented 2 car garage, 4 SCFM hydrogen leak for 20 minutes.

Blue: 0.82% hydrogen, Red: 4.1% hydrogen

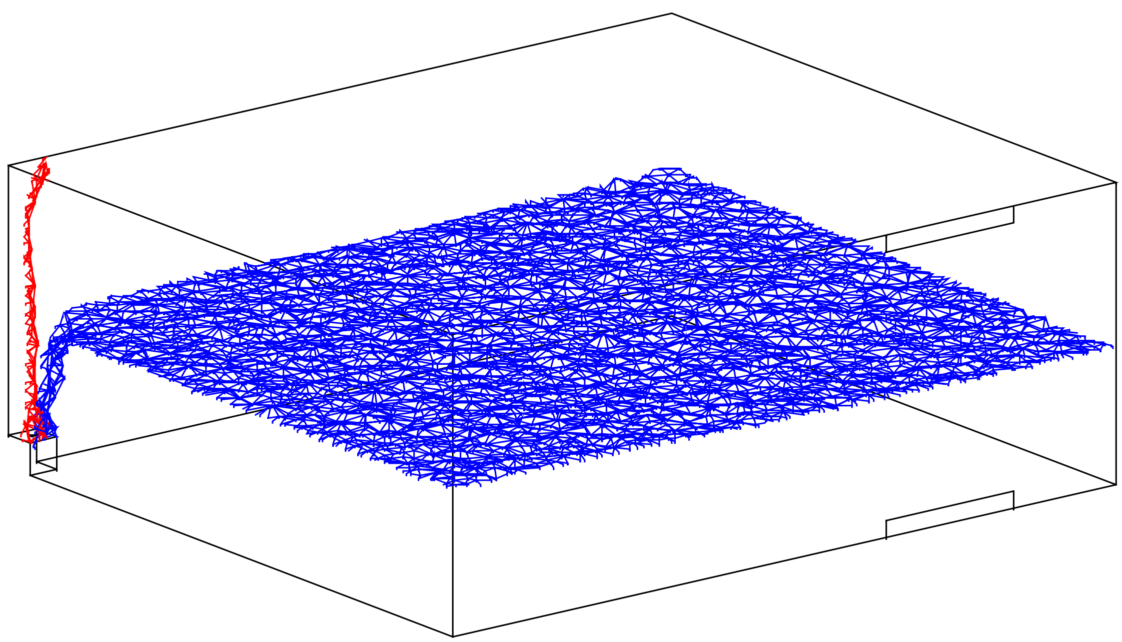


Figure C 8 - Vented 2 car garage, 4 SCFM hydrogen leak for 53 minutes.

Blue: 0.82% hydrogen, Red: 4.1% hydrogen