KY Professional Engineers in Mining Seminar (PEM)

August 19, 2022

Case Studies Related to Deep Cut Continuous Mining and Large Underground Stone Mines

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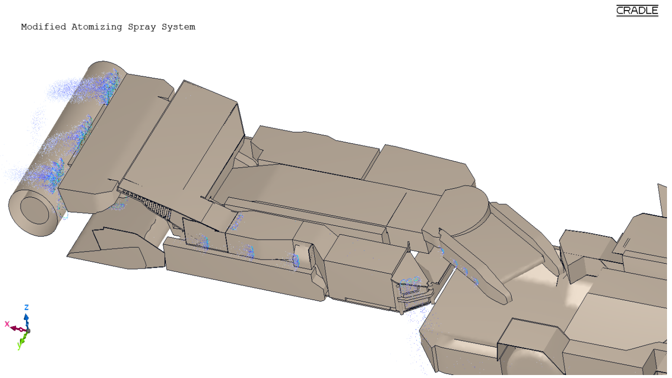
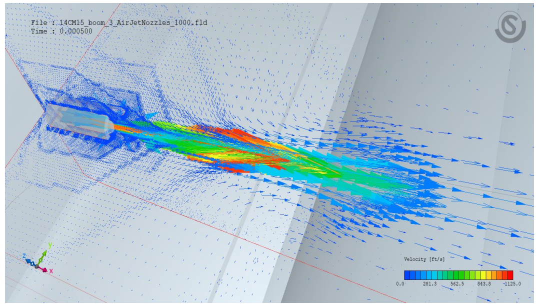
Turbulence Analytics

Outline

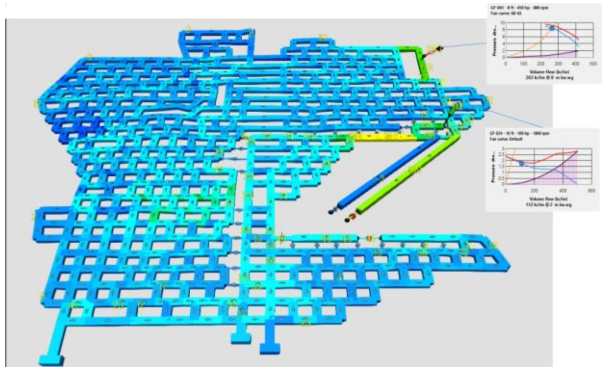
1. Supplemental Atomizing Spray System for Dust Control in Deep Cut Continuous Mining



2. Machine Mounted Air Jet System Designed to Boost Methane Dilution in Deep Cut Continuous Mining



3. Improvement of environmental conditions in a large underground stone mine after changes in mine ventilation layout. Blast clearance analysis, tracking dynamic changes in concentration of CO, NOx and dust emissions.



Acknowledgements

D. Turner

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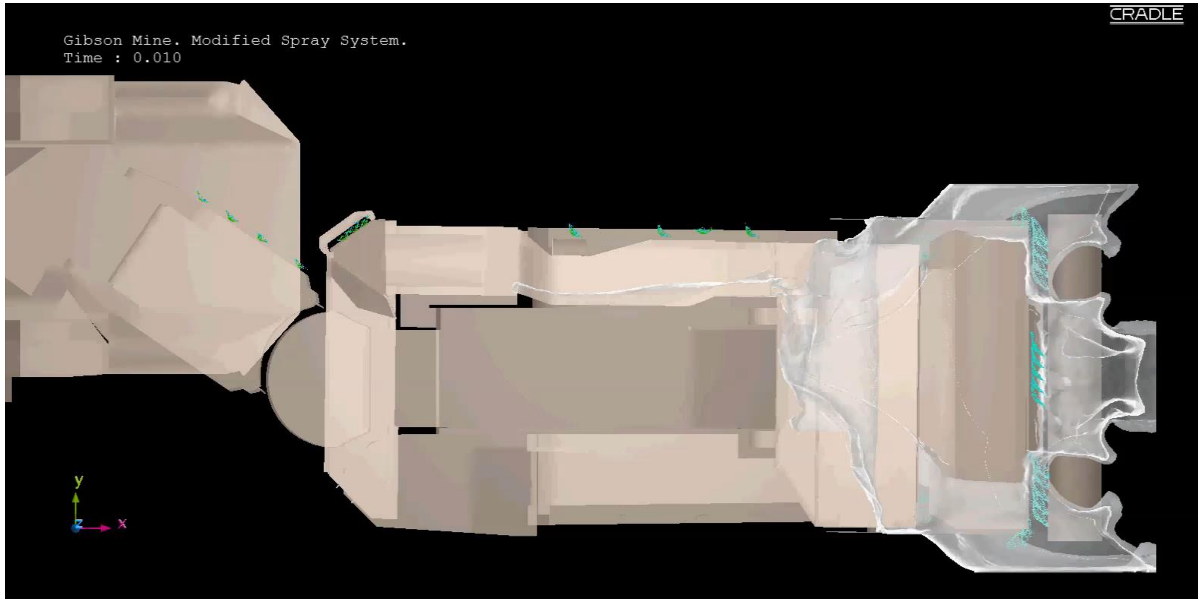
Supplemental Atomizing Spray System for Dust Control in Deep Cut Continuous Mining

Turbulence Analytics

Introduction

In efforts to improve dust control during deep cut continuous mining a supplemental atomizing spray system, mounted on 14CM15 continuous miner, has been designed and tested in working environment.

- The work on this project have started with analysis of conventionally applied face ventilation layouts.
- The study includes in-mine measurements and computer modeling.
- A computer modeling methodology have been developed for estimation the respirable dust concentration (RDC) by tracer gas.



Computational Fluid Dynamics (CFD) Analysis
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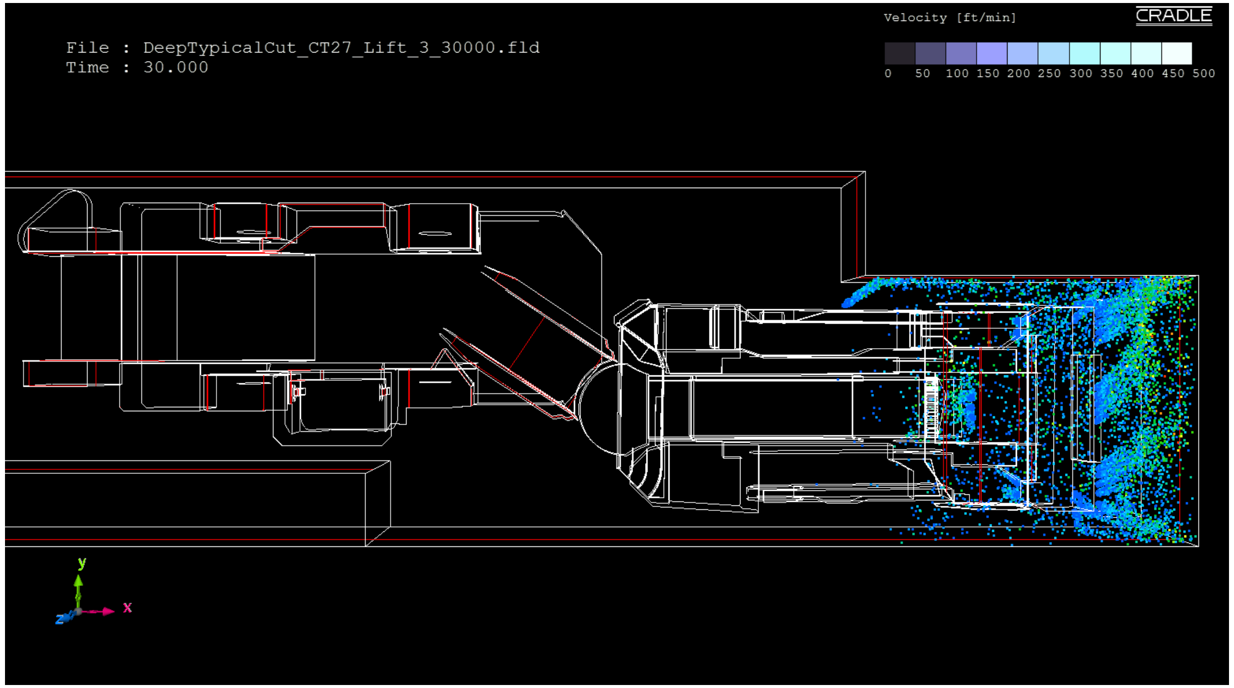
Study of the Conventional Spray System Performance

Study of the Conventional Spray System Performance

Face Ventilation Parameters

- Total flow through the last open crosscut was set to 20,000-cfm.
- The line curtain flow rate was set to 9,000 cfm and the remaining bypass air quantity of 11,000 cfm is directed past the curtain wing (not going into the line curtain).
- The CM scrubber flow rate was set to 8,000 cfm)
- Three dimensional hollow cone spray patterns and droplet size distribution of 47 BD-3 nozzles were simulated according to the provided spray layout configuration.
- Scrubber dust removal efficiency was set to 85%.



Tracer Gas to RDC Methodology

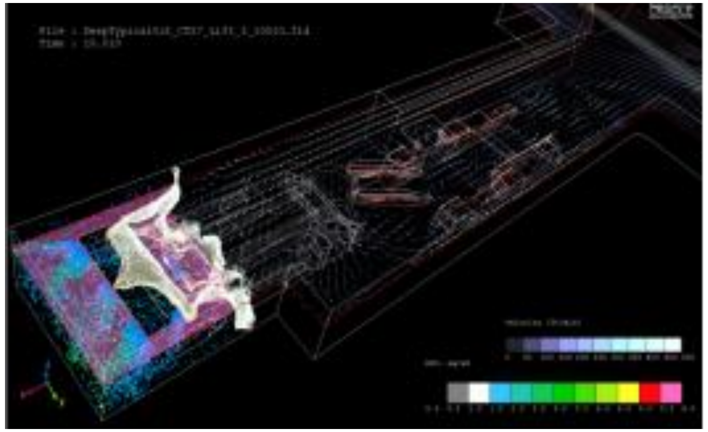
$$RDC = T_{exp}\, k_w\, C(t) + C_0\, ,\ [mg/m^3]$$

- where:
- t = time, [sec]
- $C(t)$ = CFD simulated tracer gas concentration in time t, [ppm]
- k_w = Calibration/weight factor to transform [ppm] SF6 into [mg] RDC
- T_{exp} = Exposure time in the shift, [sec]
- C_0 = Initial respirable dust concentration, [mg/m^3]

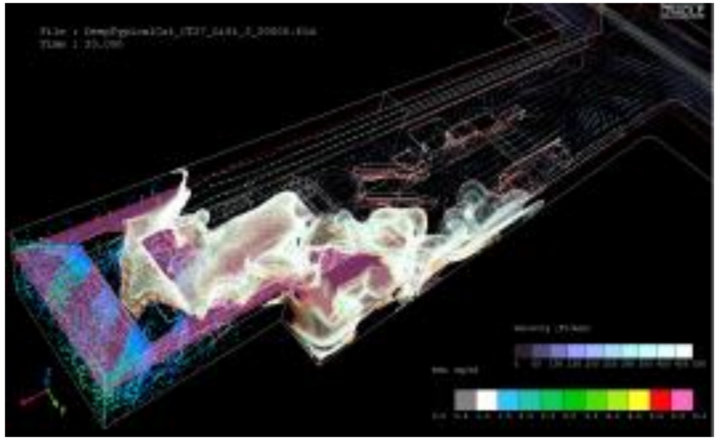
- The validity and applicability of this methodology has been evaluated in practice over the last years comparing simulation results against measurement data, and has proven to provide acuratel results in agreement with the average measured values.

Study of the Conventional Spray System Performance

Box Cut



10 sec



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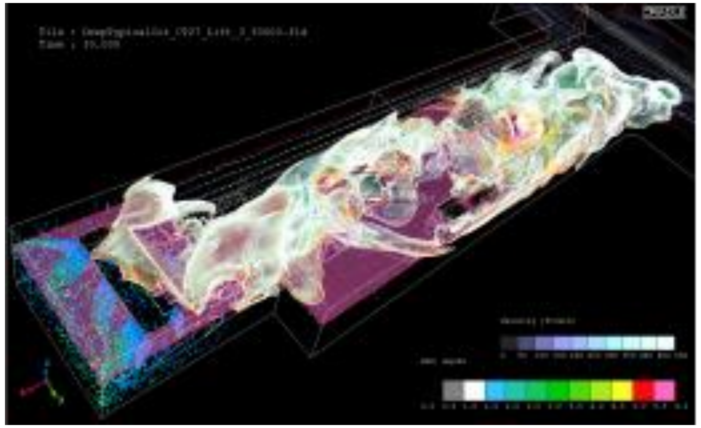
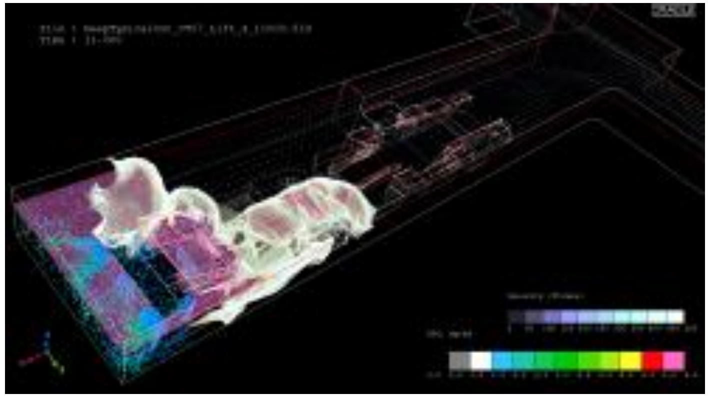
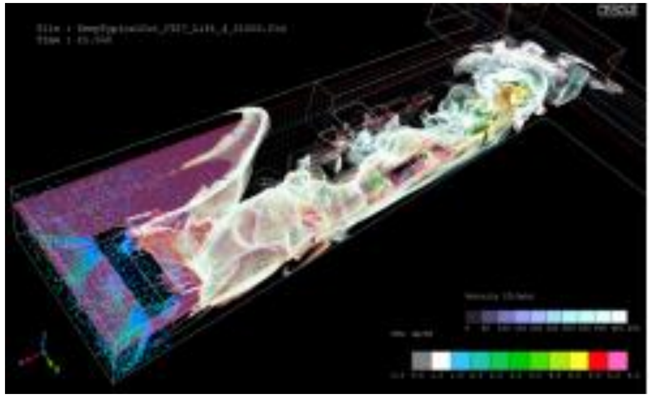
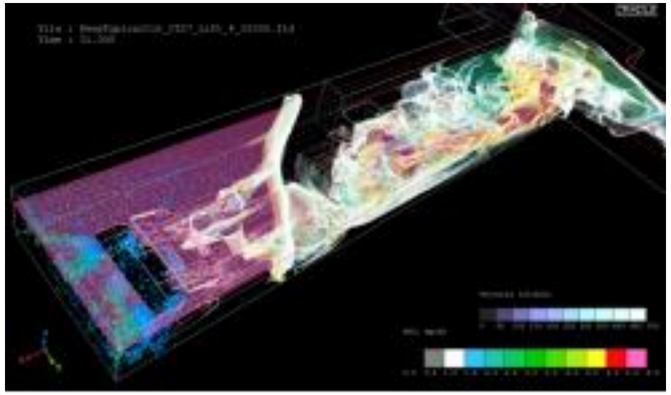


30 sec

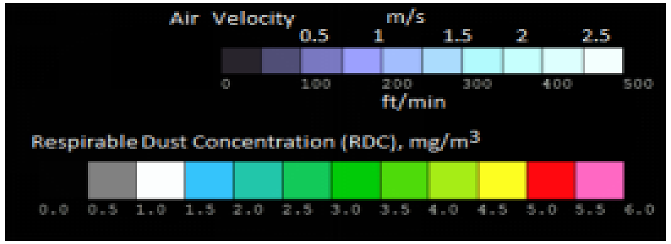
Slab Cut







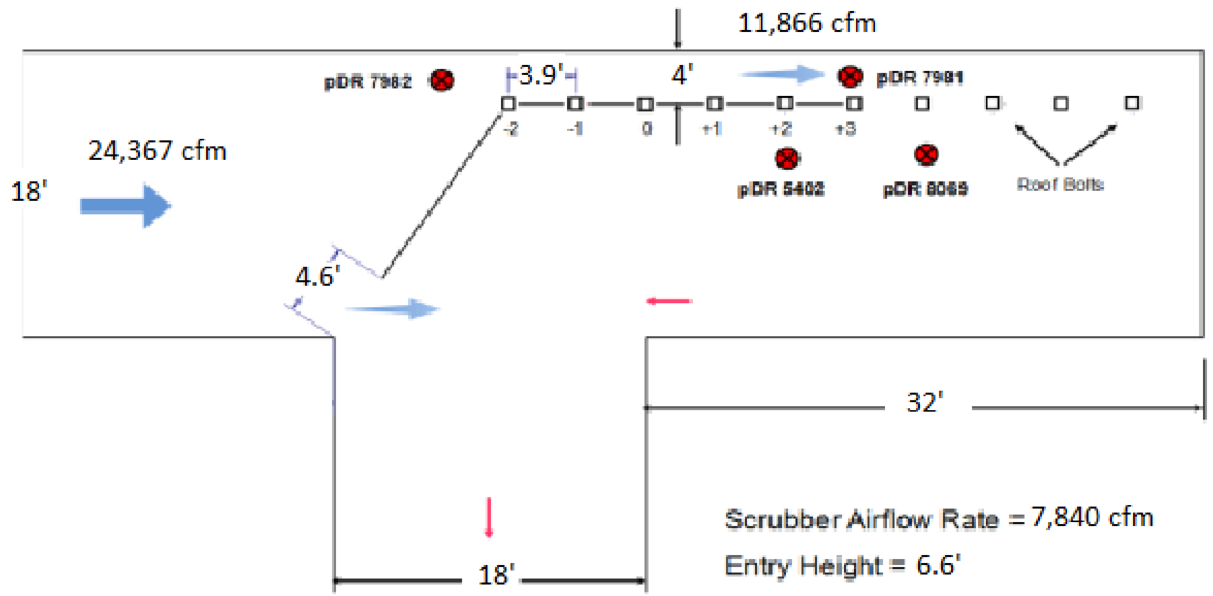
A significant part of the dust generated at the face during the coal cutting remains airborne and flows away from the scrubber inlets.



Study of the Conventional Spray System Performance

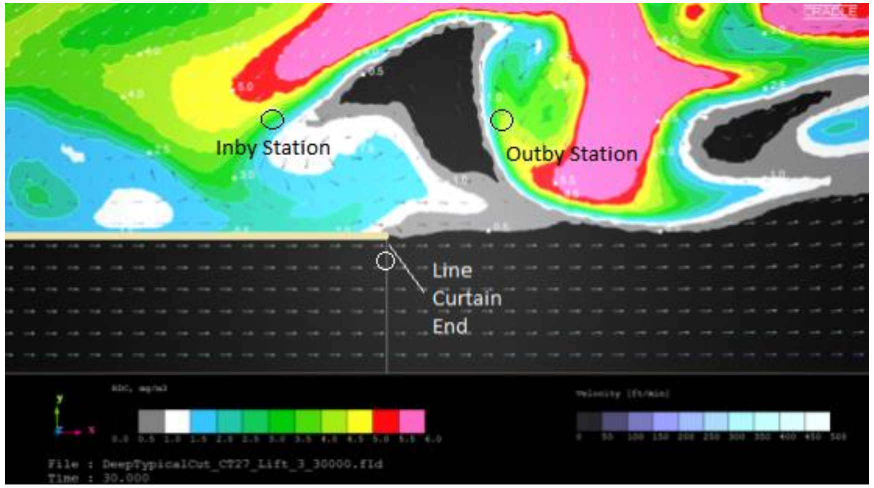
In-mine measurements

- The test was conducted for a 20-ft deep cut, left hand side line curtain setup.
- Four DataRAM™ pDR-1000AN (pDR) instruments were used, configured to record averaged dust concentration every 5 seconds .

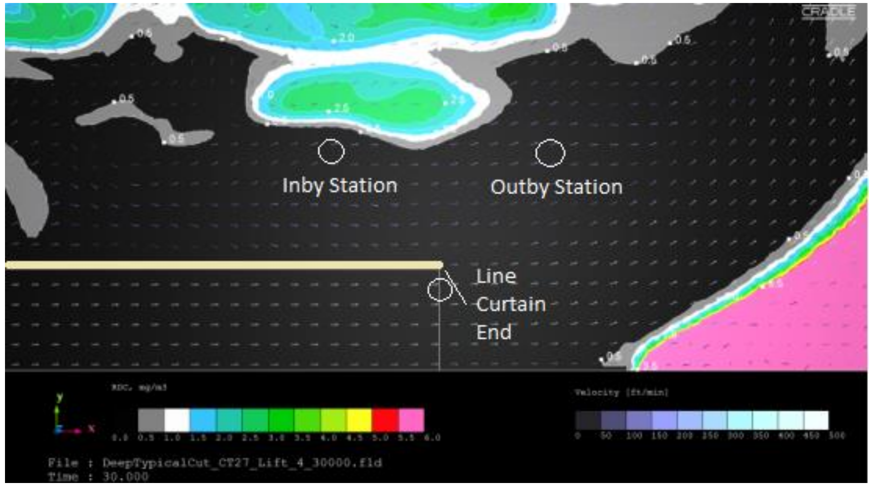


Study of the Conventional Spray System Performance

- The data for the intake dust concentration showed a steady level around 0.25 mg/m^3
- The average concentration measured at the curtain end was 0.75 mg/m^3, which indicates that the return air stream is mixing with the intake air.
- The average concentration measured at the Inbye Station was 3.1 mg/m^3 and at the Outby Station - 2.6 mg/m^3.
- For box cut scenario, the simulation showed concentrations of 3 to 5 mg/m^3 in the spot around the location of the Inbye Station, and 2 to 4 mg/m^3 in the spot of the Outby Station.
- For the slab cut scenario, the simulation showed concentrations less than 0.5 mg/m^3 for both stations.
- The observed flow direction at the return side of the line curtain was toward the face, as predicted by the computer simulations



Box cut scenario

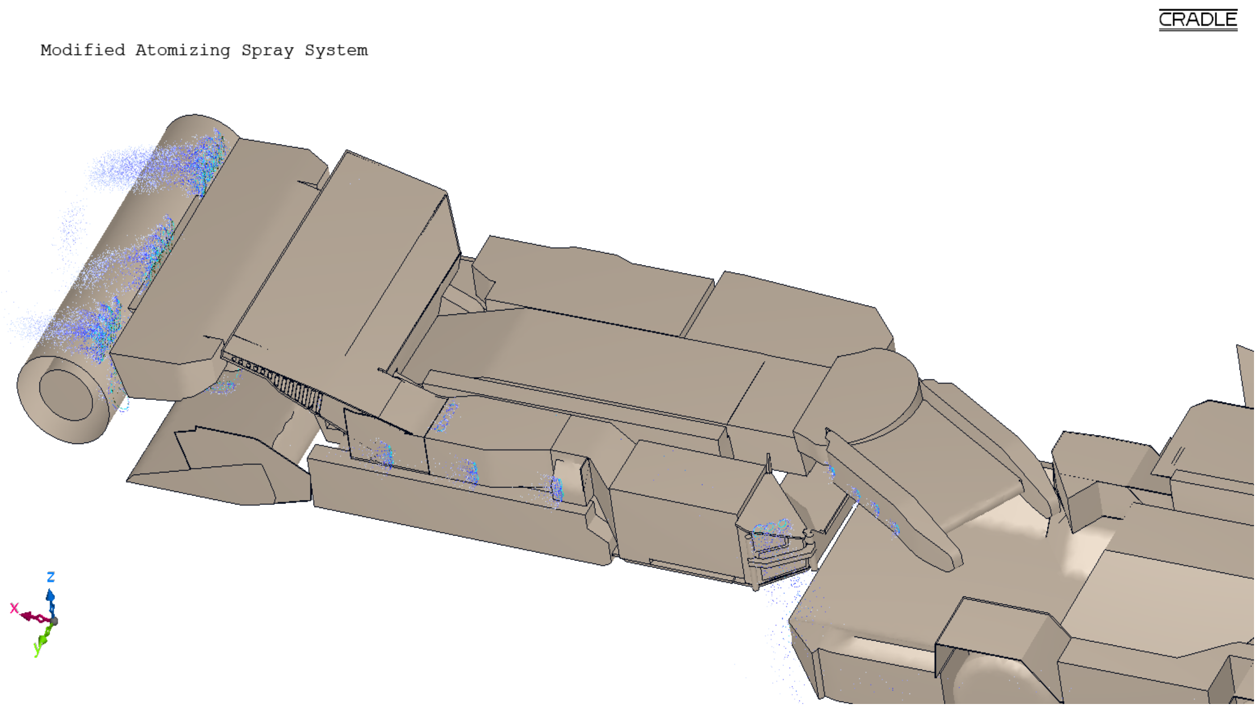


Slab cut scenario

Suplemental Atomizing Spray System

Suplemental Atomizing Spray System

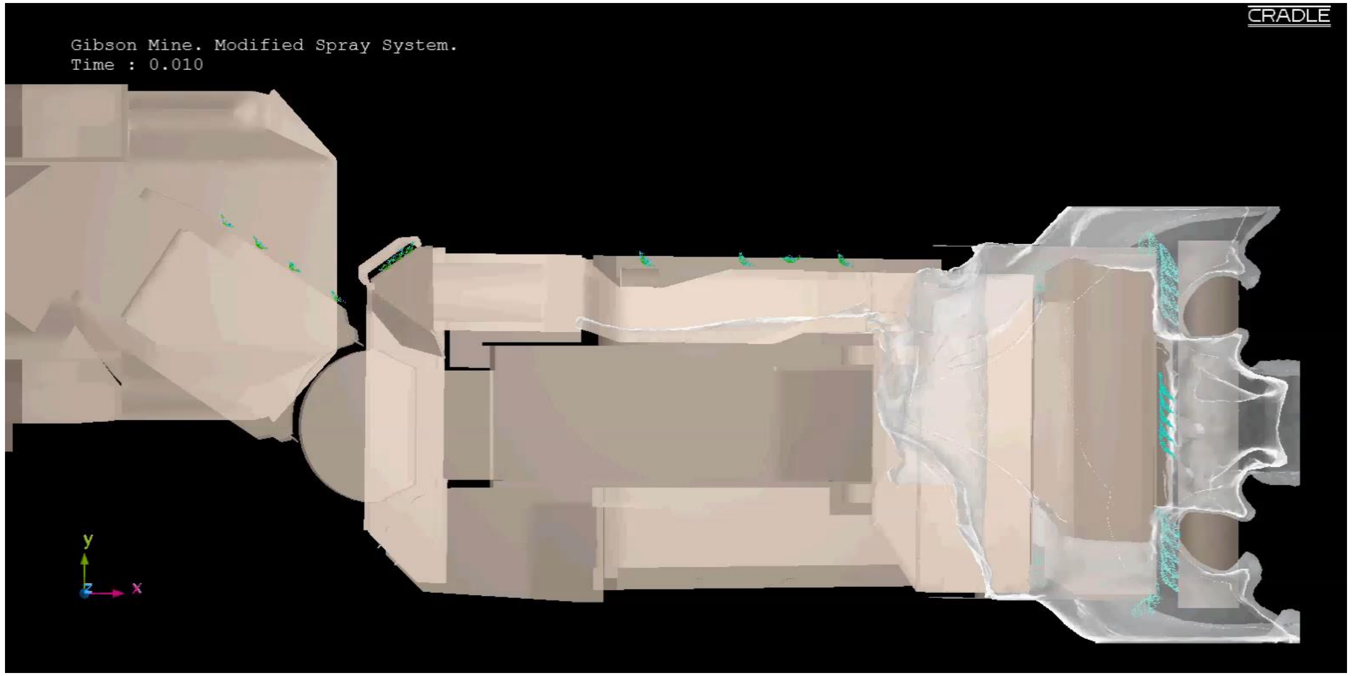
- After a detailed study of the conventional spraying system performance and a number of prospective solutions for improvement beng analized, one design was selected.
- A supplemental spray system with atomizing spray nozzles have been proposed by Z. Brown and J. Dilbeck.
- The system consists of 18 atomizing spray nozzles A250 and A300.



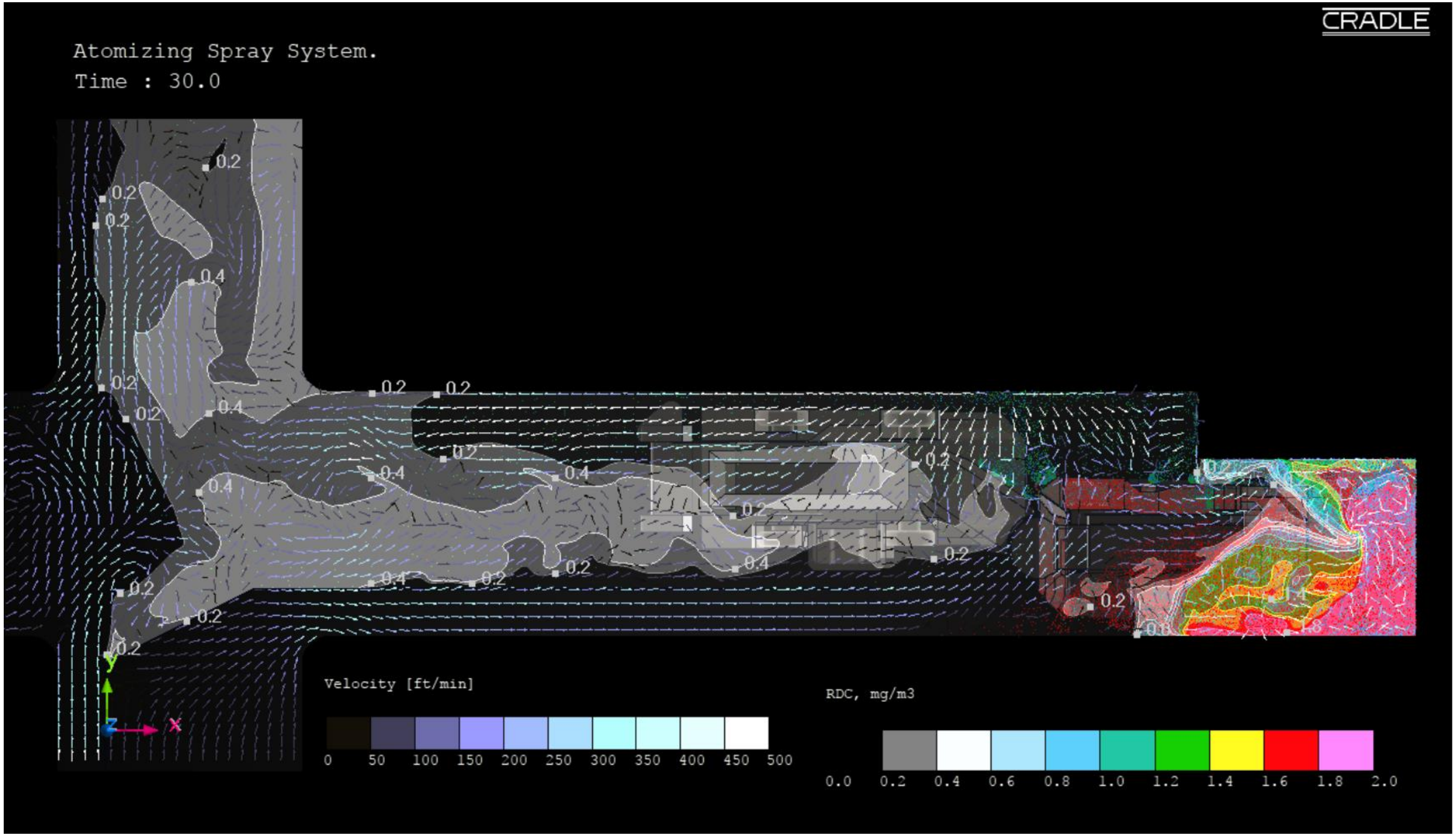
Suplemental Atomizing Spray System

- The operating water line pressure of the atomizing spray system is 2,070 kPa (300-psi). At this operating pressure, the system uses about 8 L/min (2.1-gpm)

- All the atomizing sprays are connected to incoming water line through a solenoid valve that is activated when the scrubber ductwork spray is activated. Thereby, when the scrubber is on, the atomizing sprays are on.



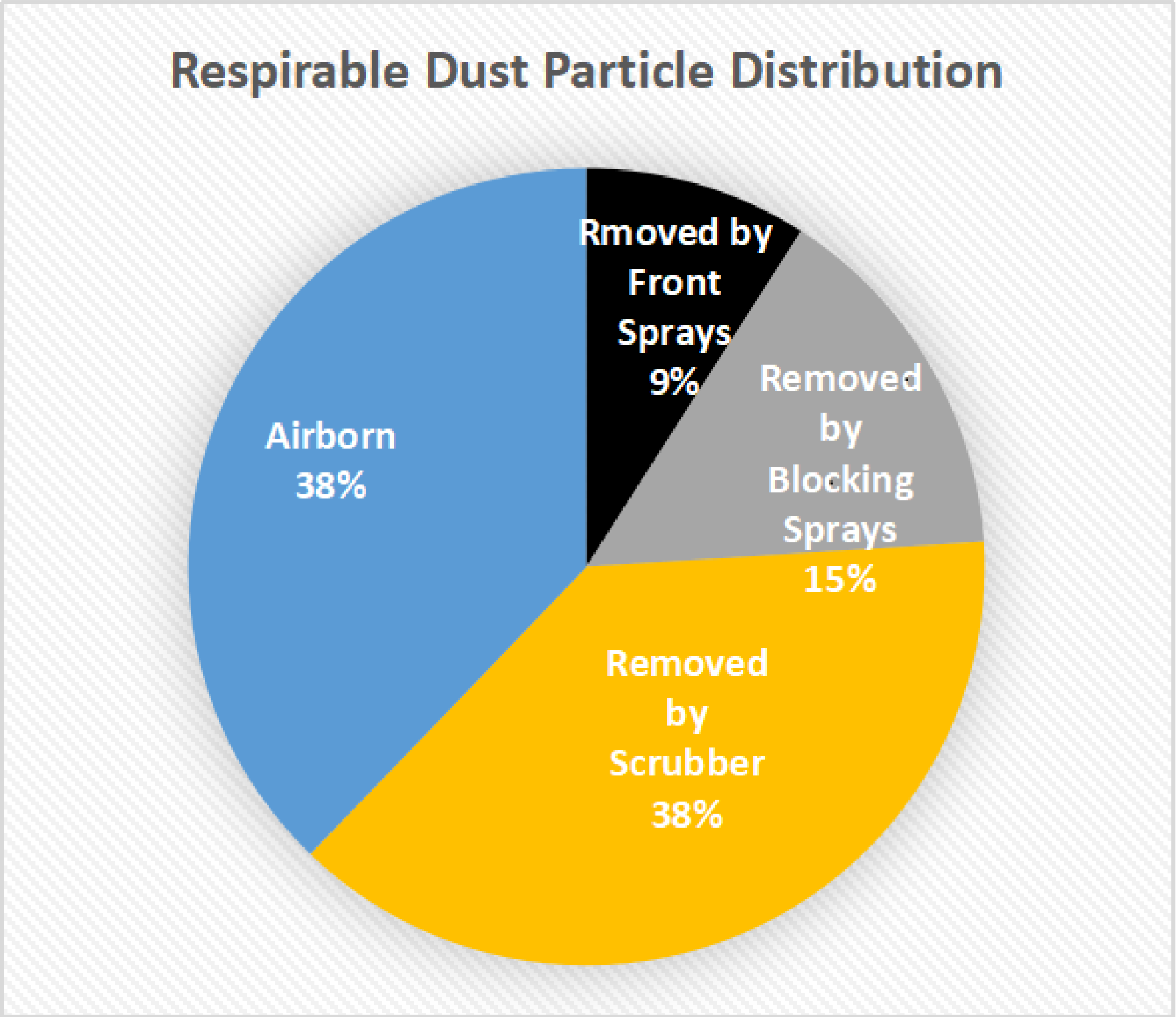
Suplemental Atomizing Spray System



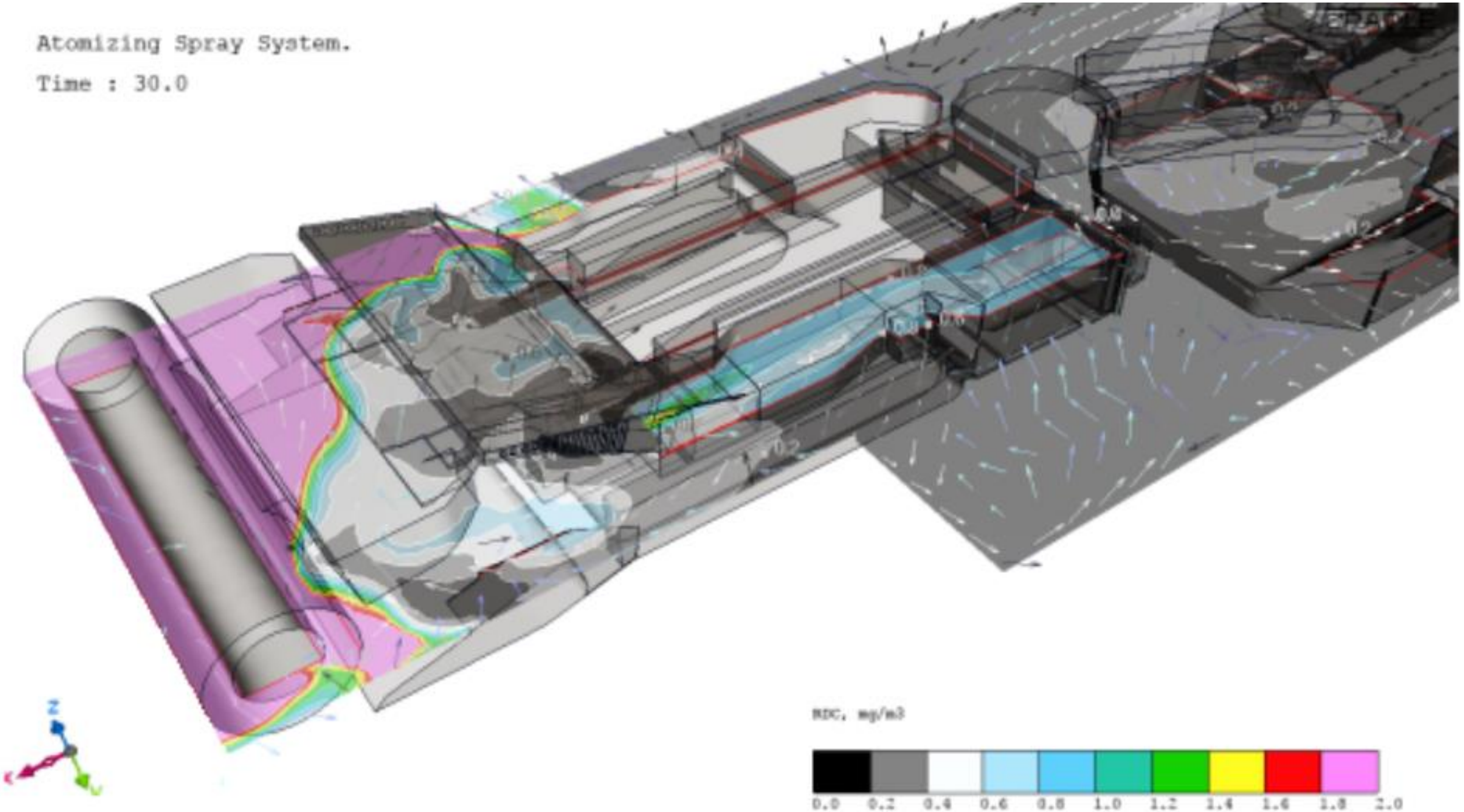
CFD Results. Atomizing spray system. Respirable dust concentration map

Suplemental Atomizing Spray System

- The in-mine measurements data have shown cumulative dust concentrations of less than 0.3 mg/m^3 at the CM operator place as well as less than 0.5 mg/m^3 at the return.

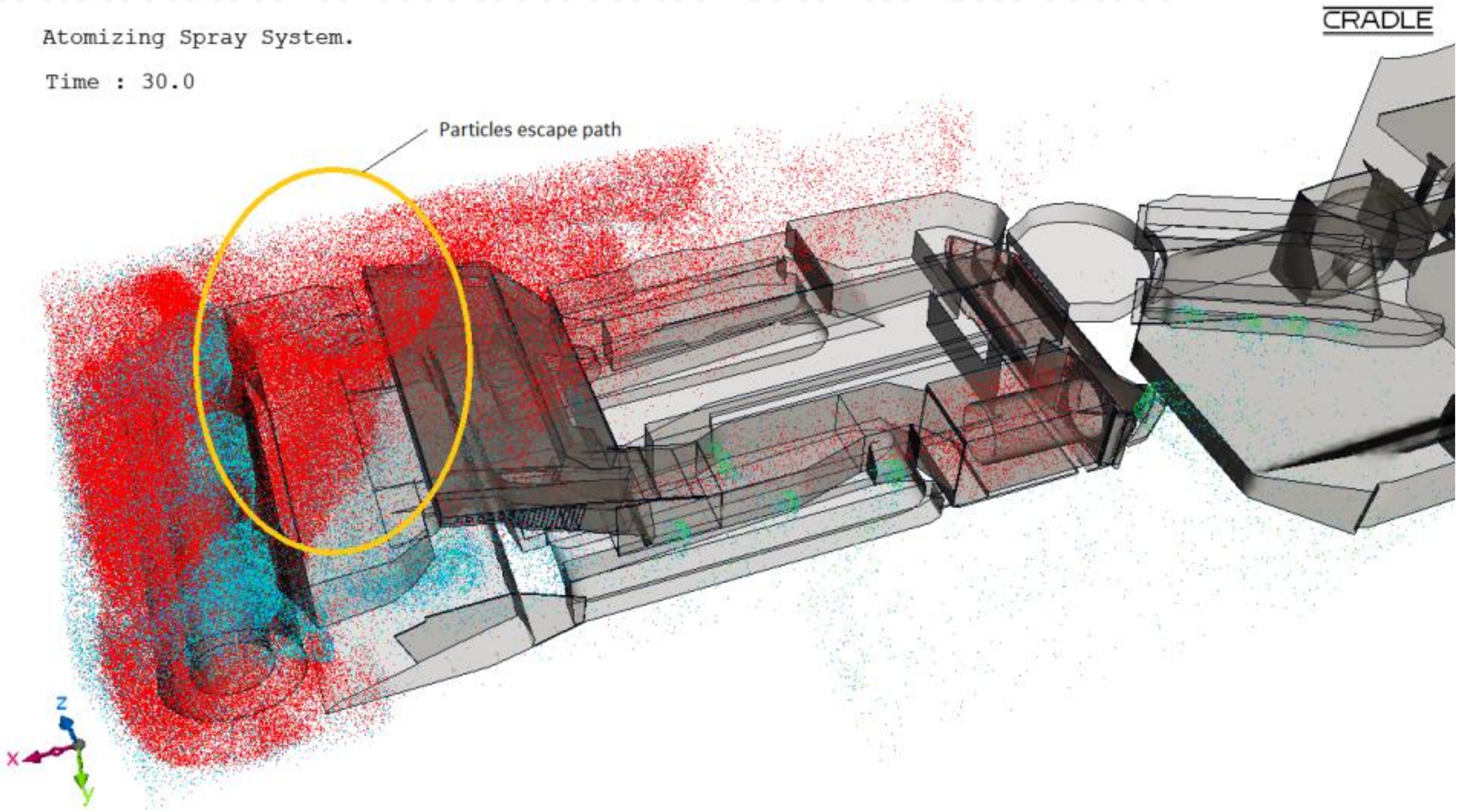


Suplemental Atomizing Spray System



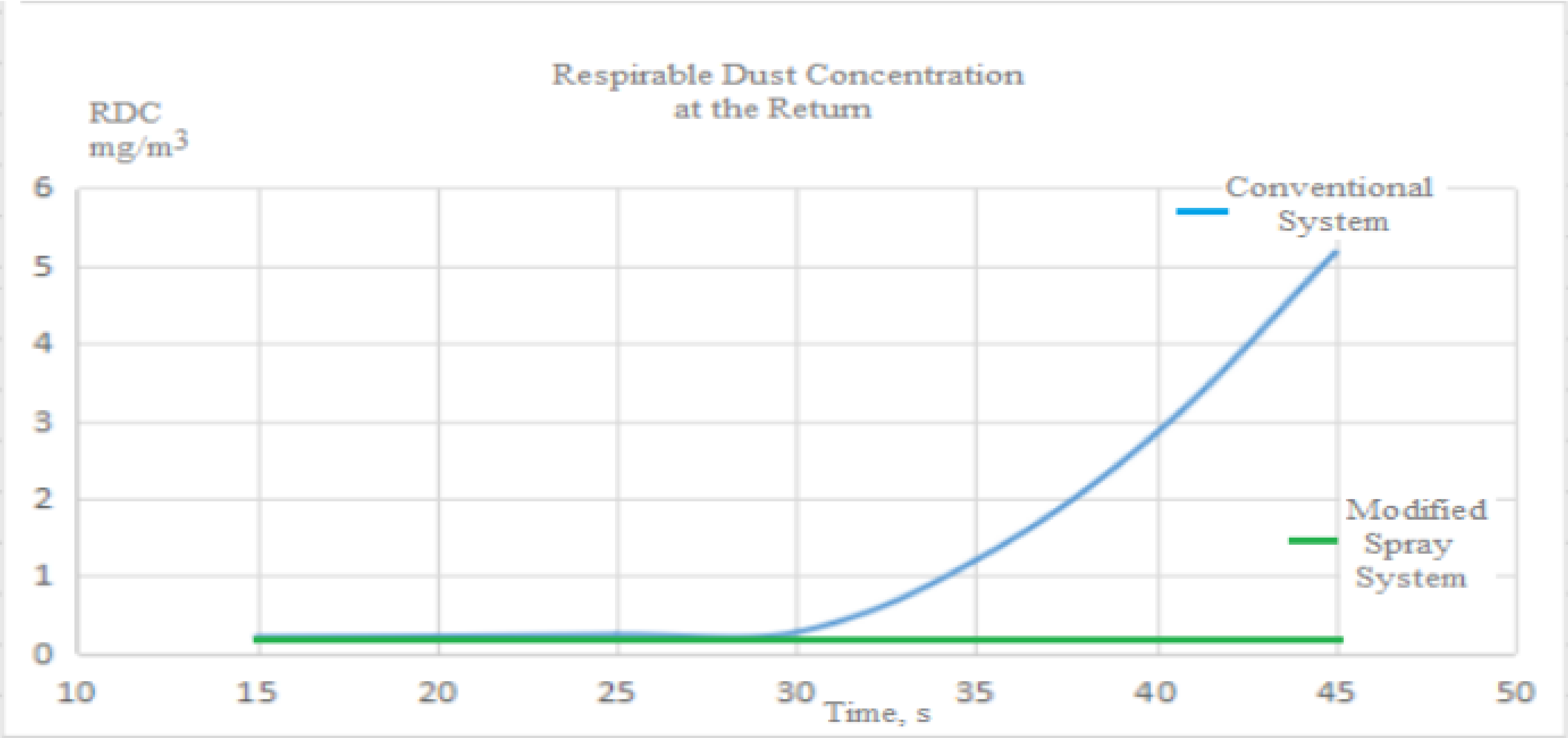
CFD Results. Respirable dust concentration map

Suplemental Atomizing Spray System



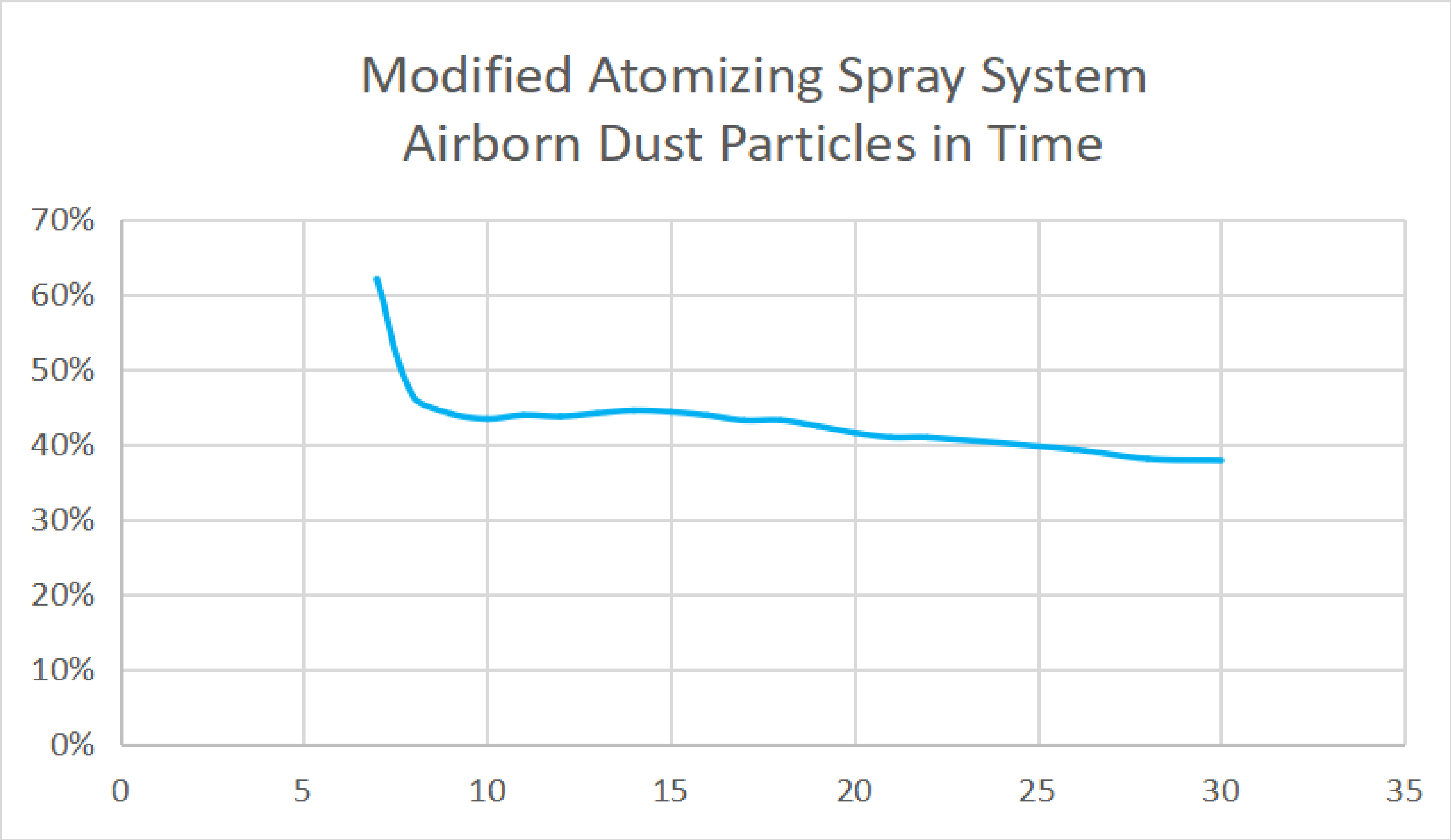
CFD Results. Respirable dust particles traking

Suplemental Atomizing Spray System



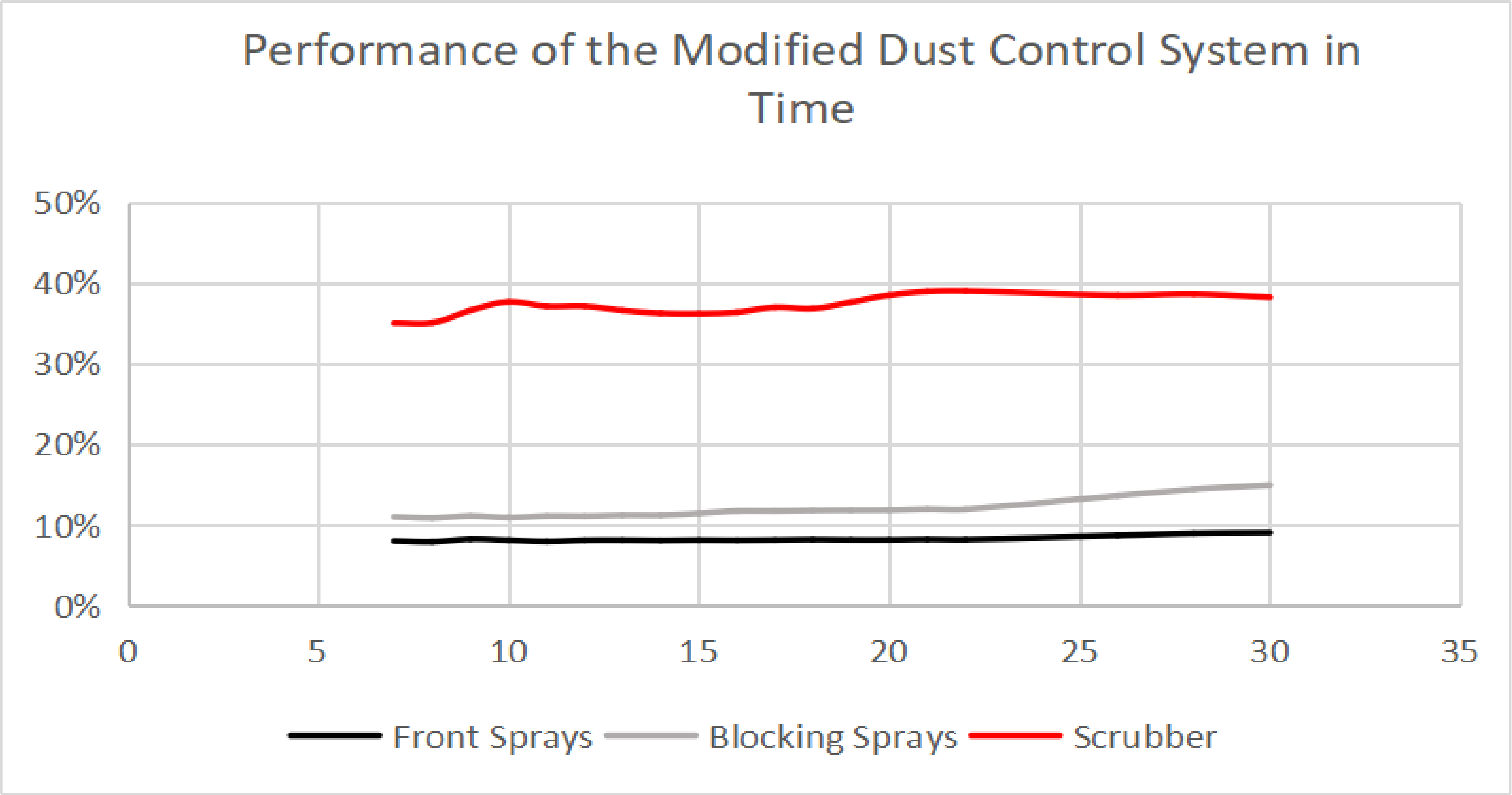
CFD Results

Suplemental Atomizing Spray System



CFD Results

Suplemental Atomizing Spray System



CFD Results

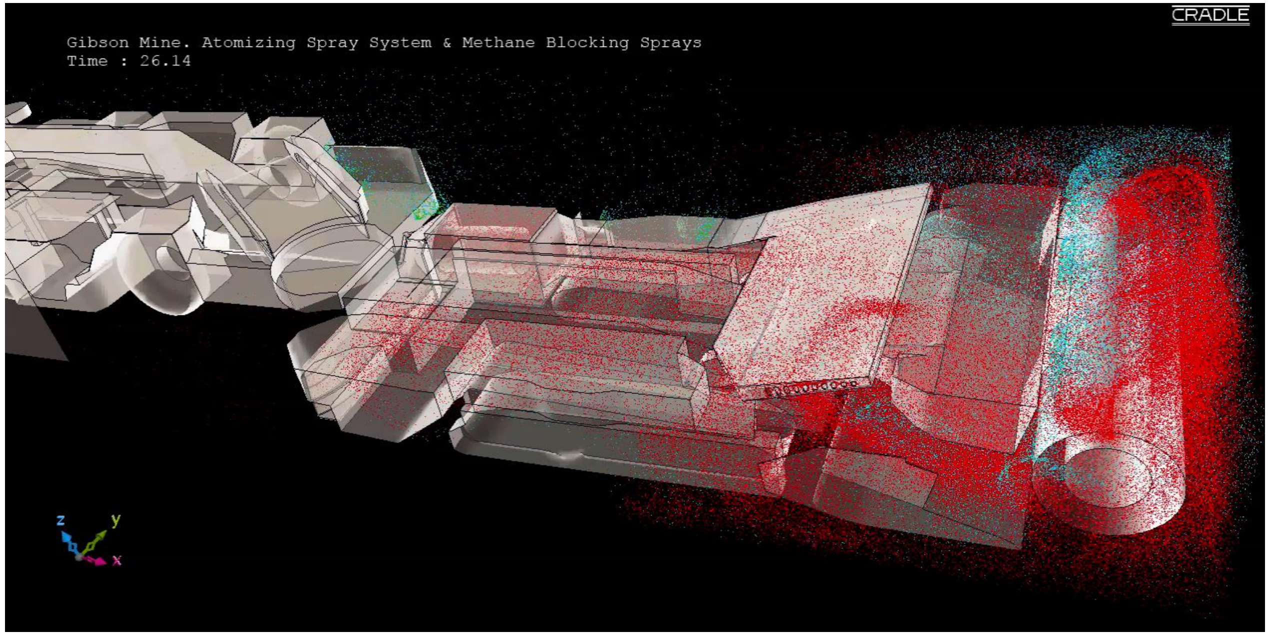
Suplemental Atomizing Spray System

CFD simulation results for the first 30 sec of simulation

Area of interest	ModifiedSpray System	Conventional Spray System
Scrubber intake performance	36%	25%
CT operator cab RDC, mg/m^3	0.2	1.5
Return RDC, mg/m3	0.28	5

Suplemental Atomizing Spray System

- The system with the blocking sprays have demonstrated better dust reduction performance.
- However, the dust cloud escape path observed under the boom still nees attention and controll.



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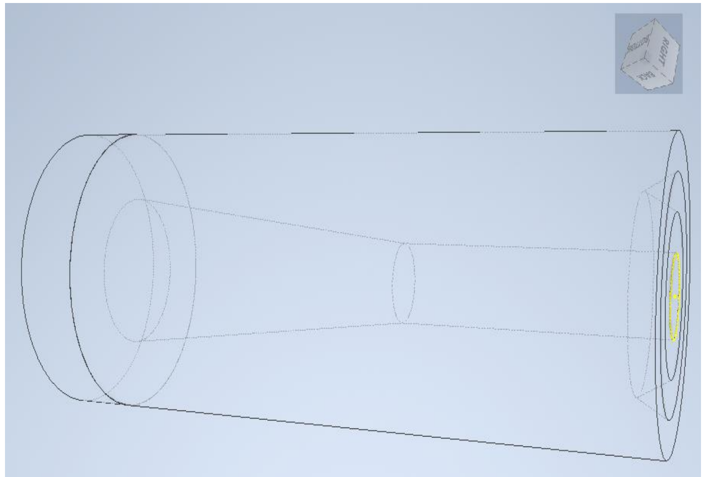
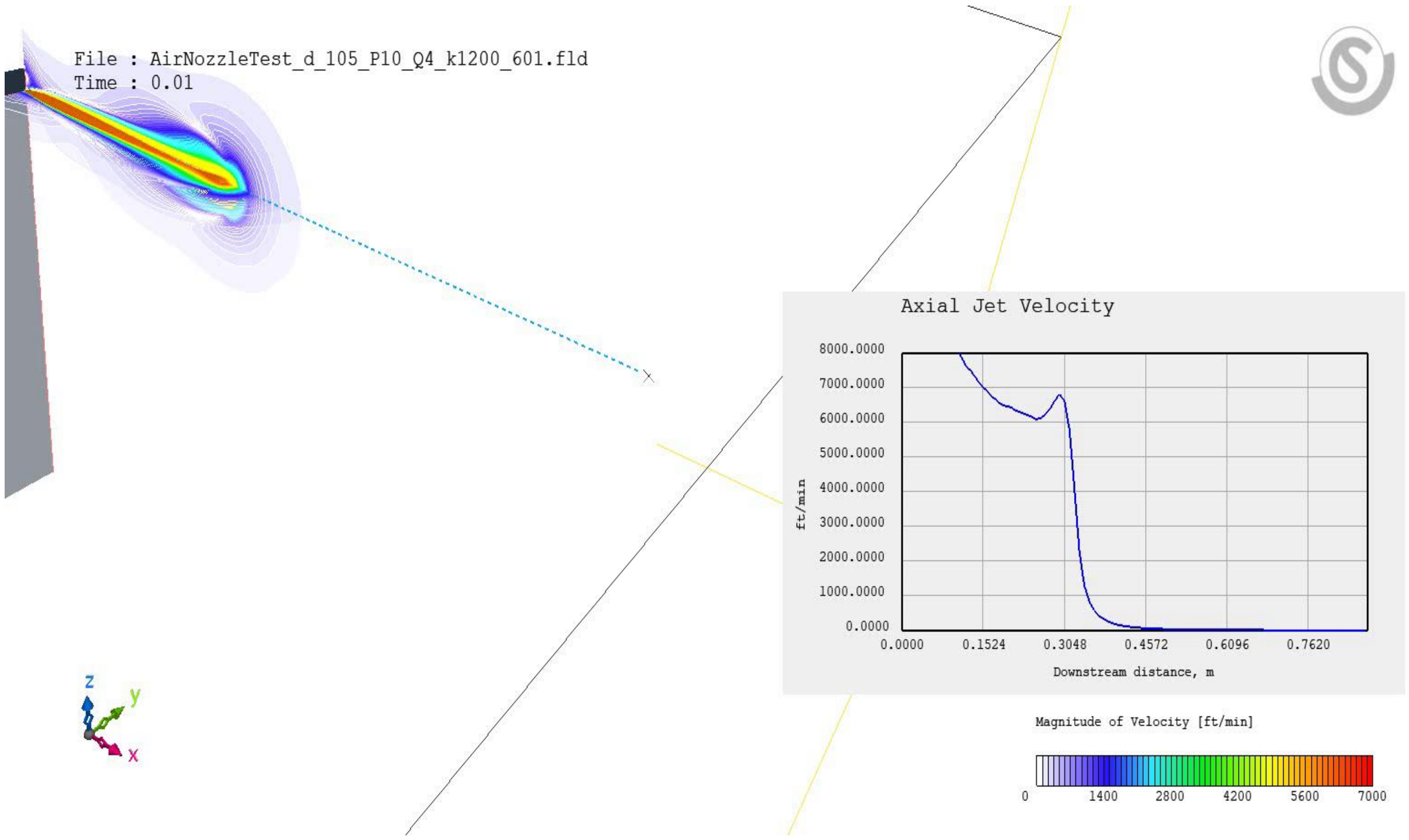
Air Jet Project



Turbulence Analytics

Introduction

- In efforts to improve methane dilution control in deep cut continuous mining an Air Jet system mounted on the continuous miner has been developed and tested.
- The effect of a single straight Air Jet Nozzles with d=0.105", initial pressure of Pi=10 psi, and entrainment air quantity Qn=4.06 cfm, on the velocity field at the immediate face area has been simulated.
- As the jet velocities are close to the speed of sound the model requires compressible air flow properties, the computational mesh is challenging and requires tiny time step to ensure stable computations.

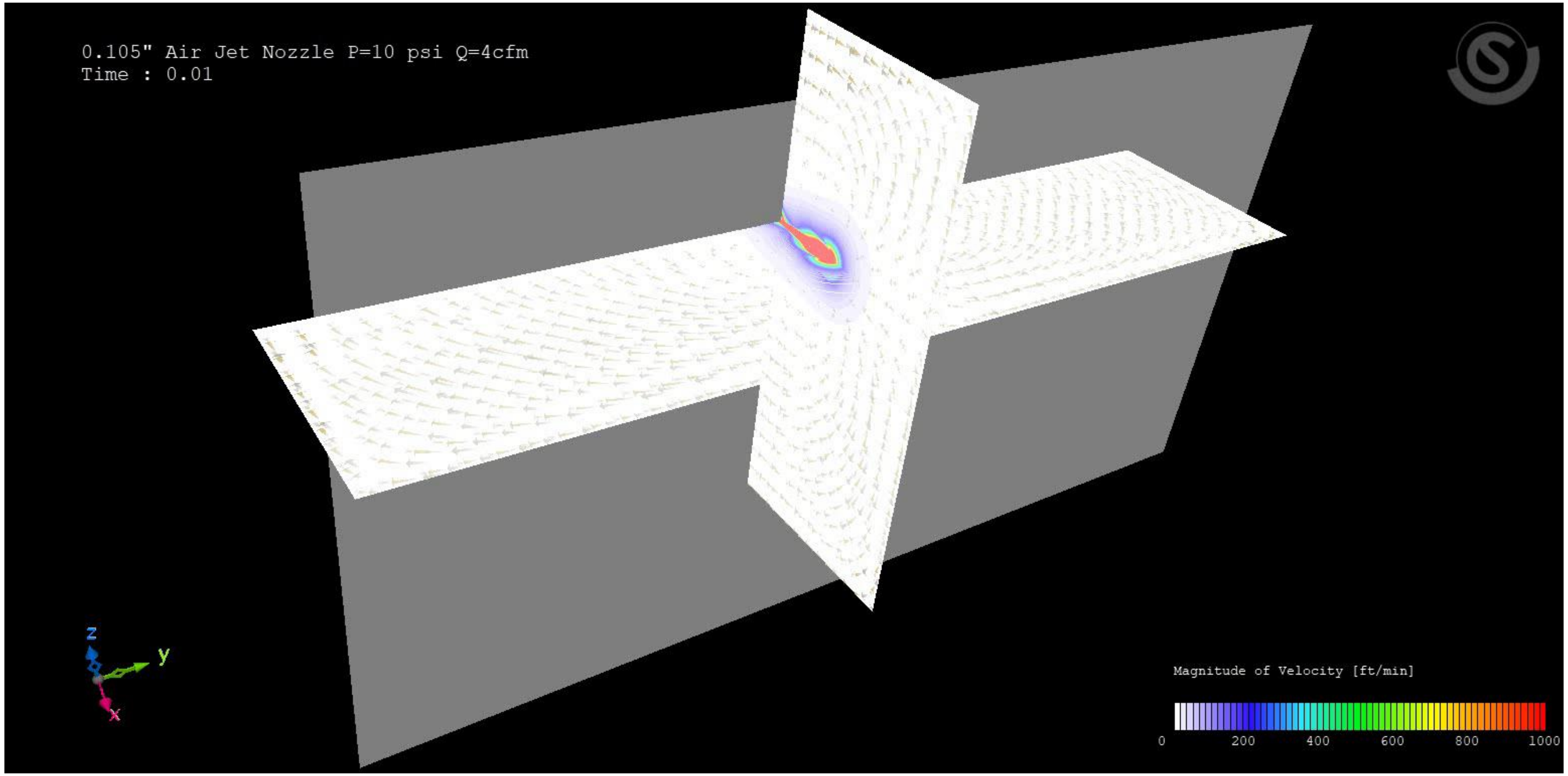


Computational Fluid Dynamics Analysis
Powered by MSC Cradle CFD scTetra

Study of a Single Air Jet Nozzle Airflow Patterns

Study of a Single Air Jet Nozzle Airflow Patterns

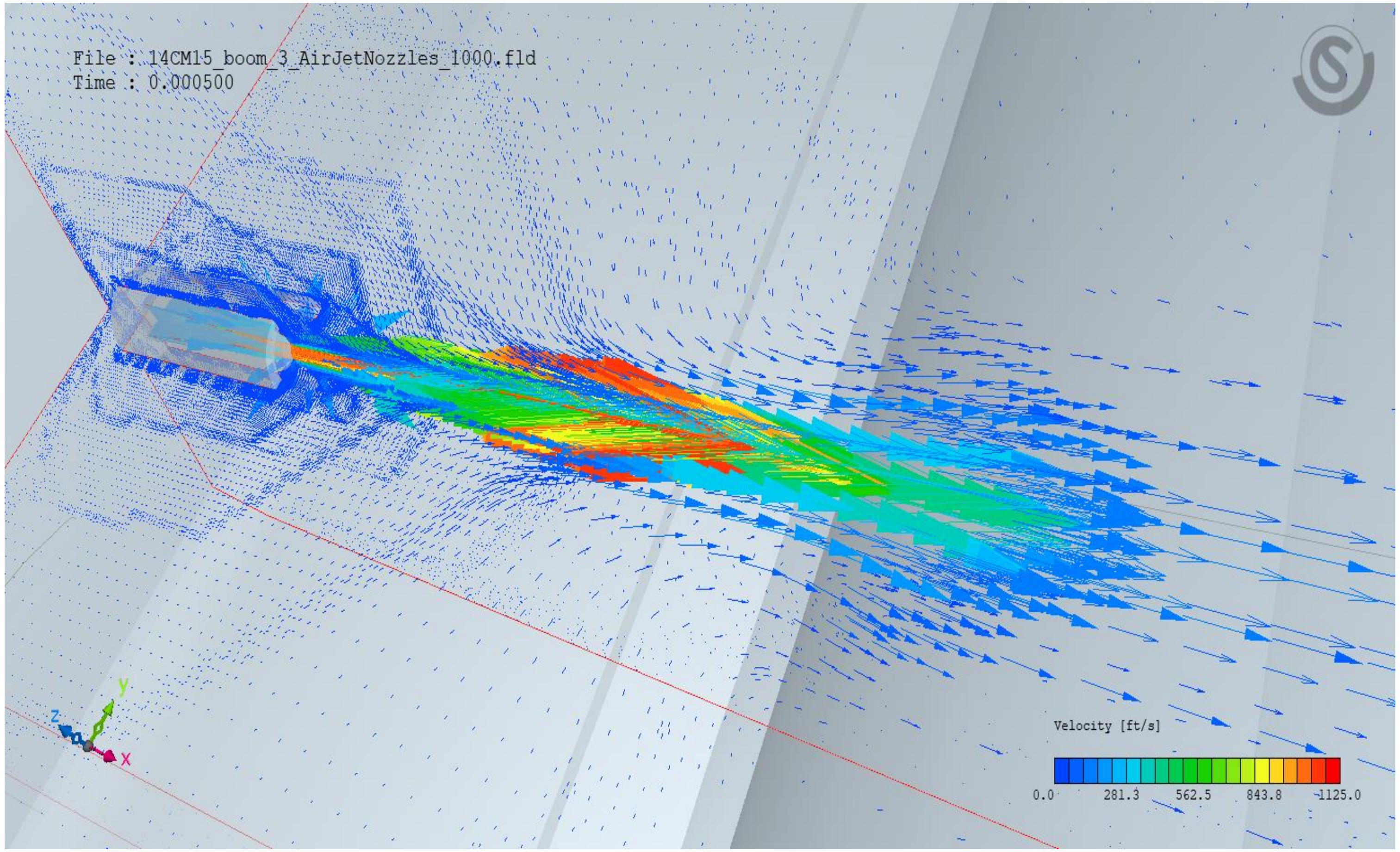
- The simulation showed, that the jet's core reaches the face in 0.2 sec
- It takes two seconds for the jets spots to cover the face
- The air jet core spot at the face is with a diameter of approximately 1 ft, reaching velocities of 12 ft/s.
- With the time advancing air velocities along the face exceed 3 ft/s.
- The induced airflow around the air jet core is forming a cylindrical volume with diameter of about 2 ft and peripheral velocity of 1 ft/s.



Study of a Single Air Jet Nozzle Airflow Patterns

Choked Flow Conditions

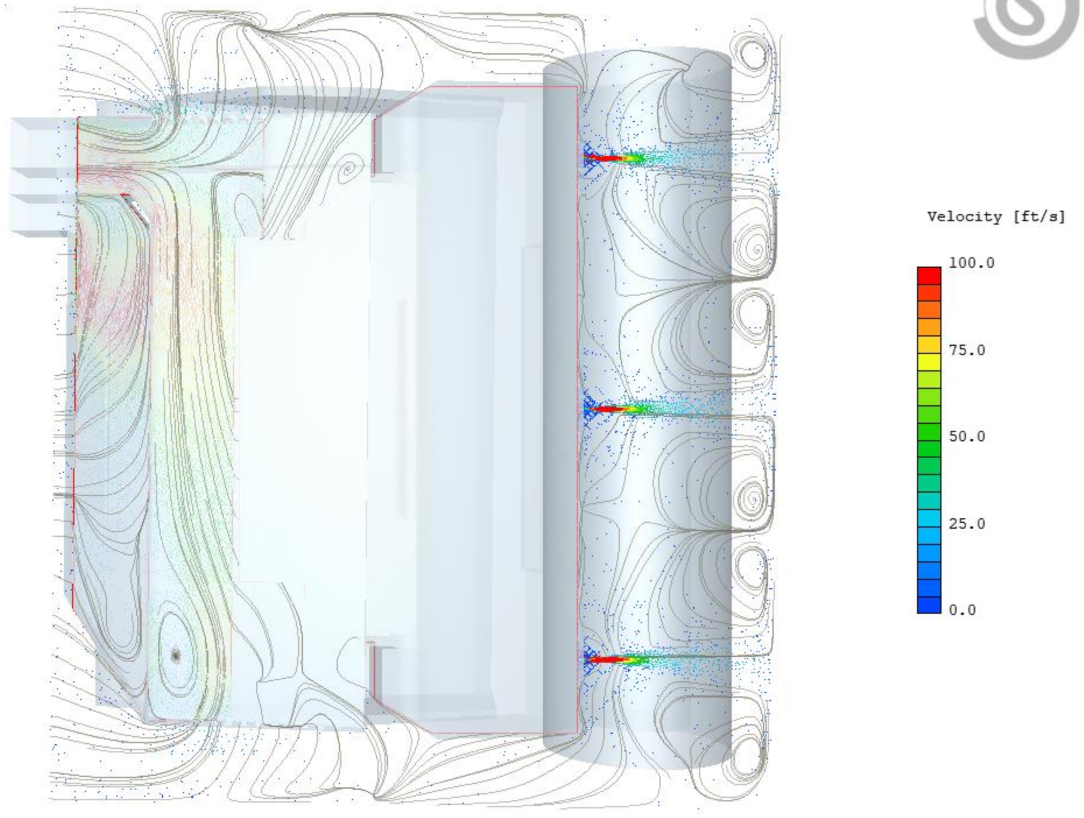
- As the initial speed of the air jet generated by the nozzle is very close to the speed of sound it can be exceeded at the discharge of the nozzle due to the Venturi effect.
- A closer look at the velocity field in vicinity of the air jet nozzle exhaust, indicate supersonic patterns.
- Under such conditions, the choked flow effect is taking place.
- In choked flow conditions, the mass flow will not increase with a further increase in the upstream pressure regardless of downstream pressure.
- In practical point of view, by keeping the exit velocity at sonic conditions, Mach ~ 1, will ensure stable mass flow rate.
- The simulation results have confirmed that the investigated nozzle maintains choked flow condition.



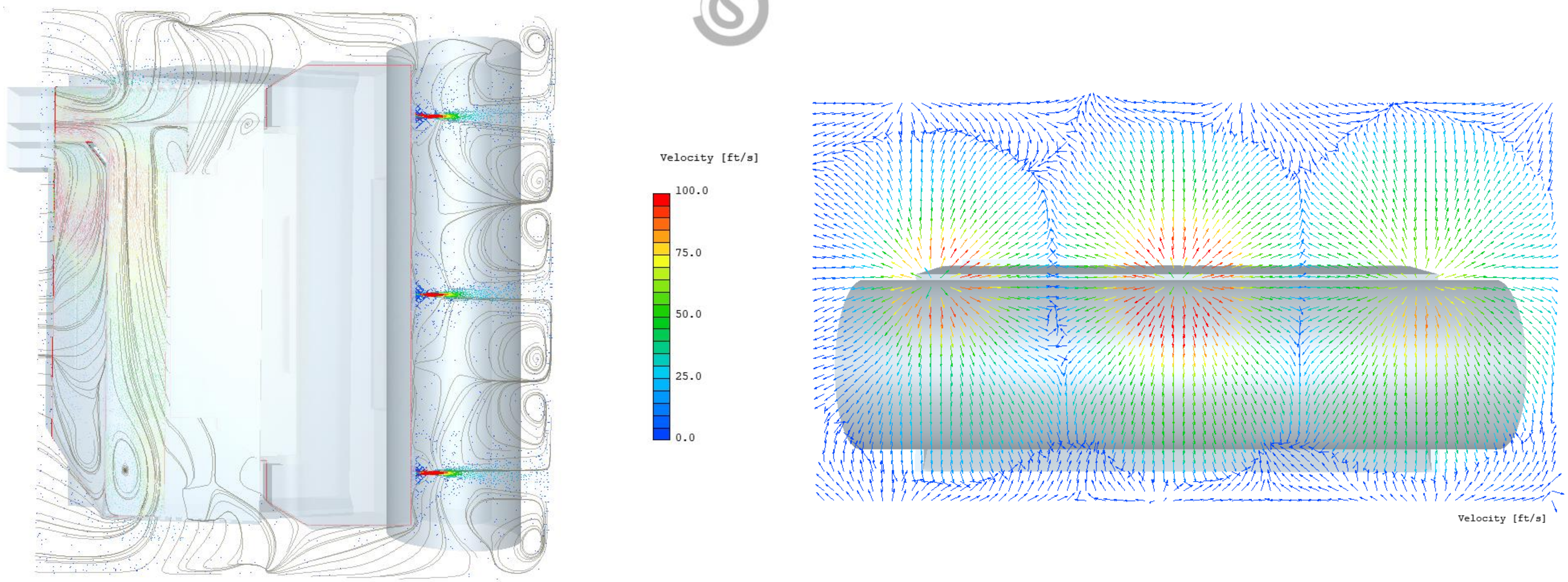
Study of Air Jet System Mounted on CM

Full Scale Computer Modeling

- The computational domain includes the front part of the CM positioned at the face of a box cut .
- The intake flow rate and the scrubber capacity were set to 9,000 cfm,
- The Scrubber triple inlet flow was distributed to 30%:40%:30%
- Three stright air jet have been simulated



Study of Air Jet System Mounted on CM



Air Jet Velocity at Face Area in 2 sec of Jet Development

Study of Air Jet System Mounted on CM

Turbulence Intensity

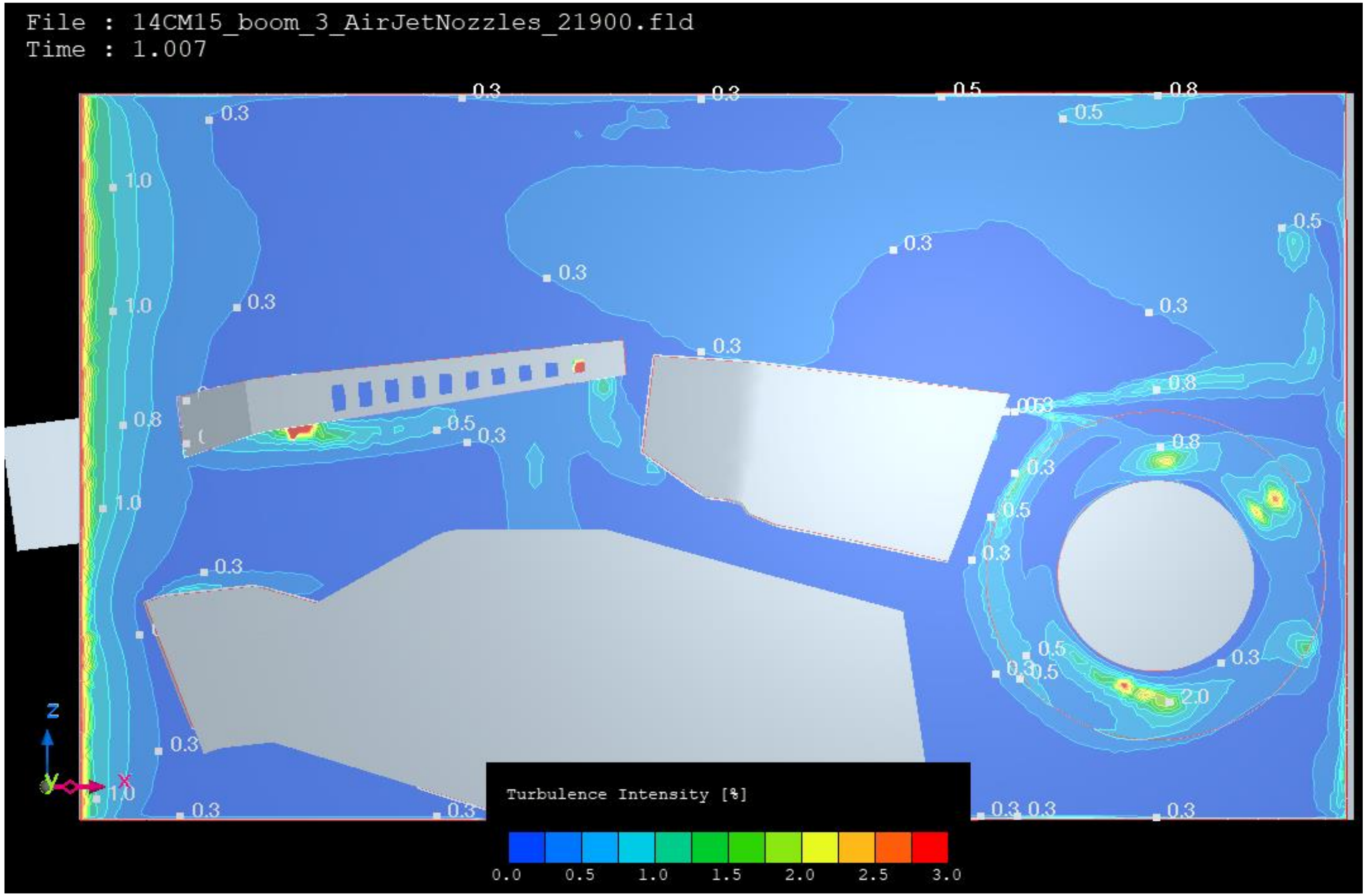
- Turbulence is one of the major factors affecting gas dilution effectiveness.

$$T_u = \frac{u'}{U}$$

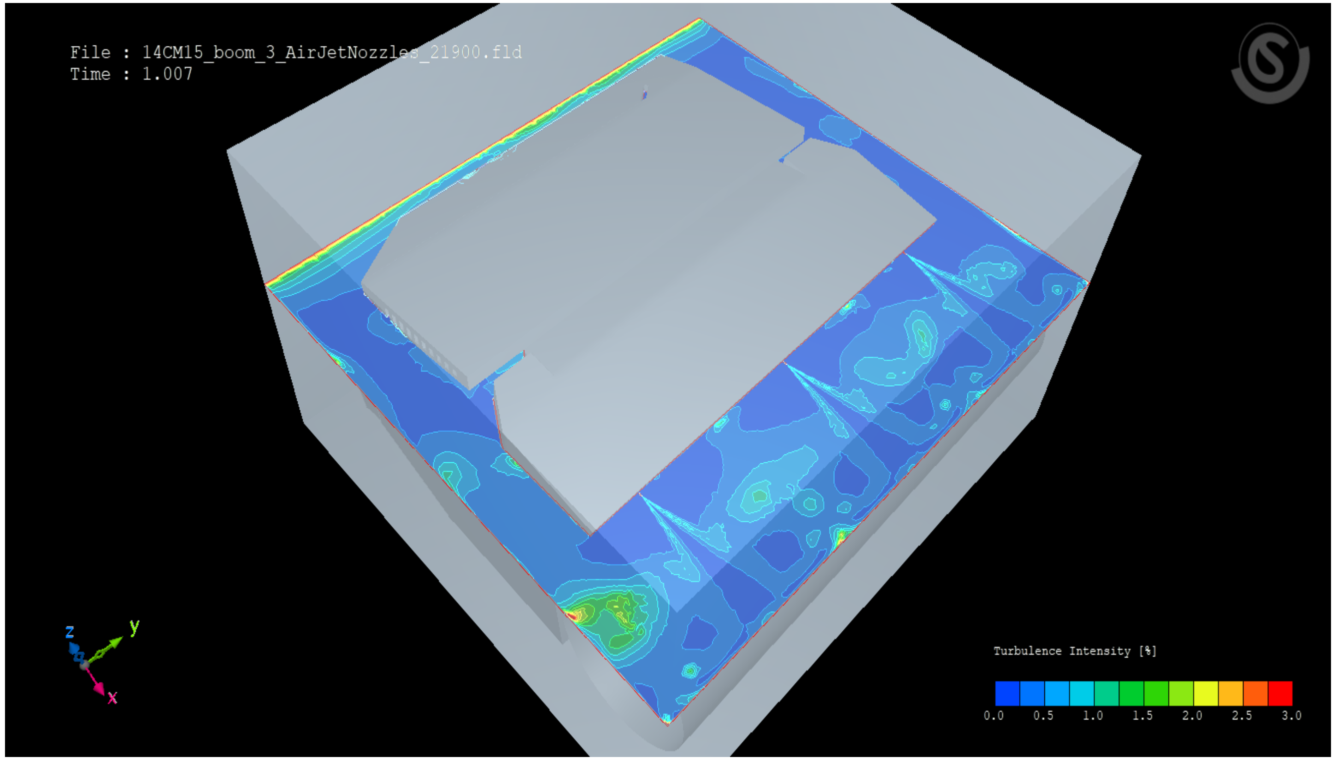
Where

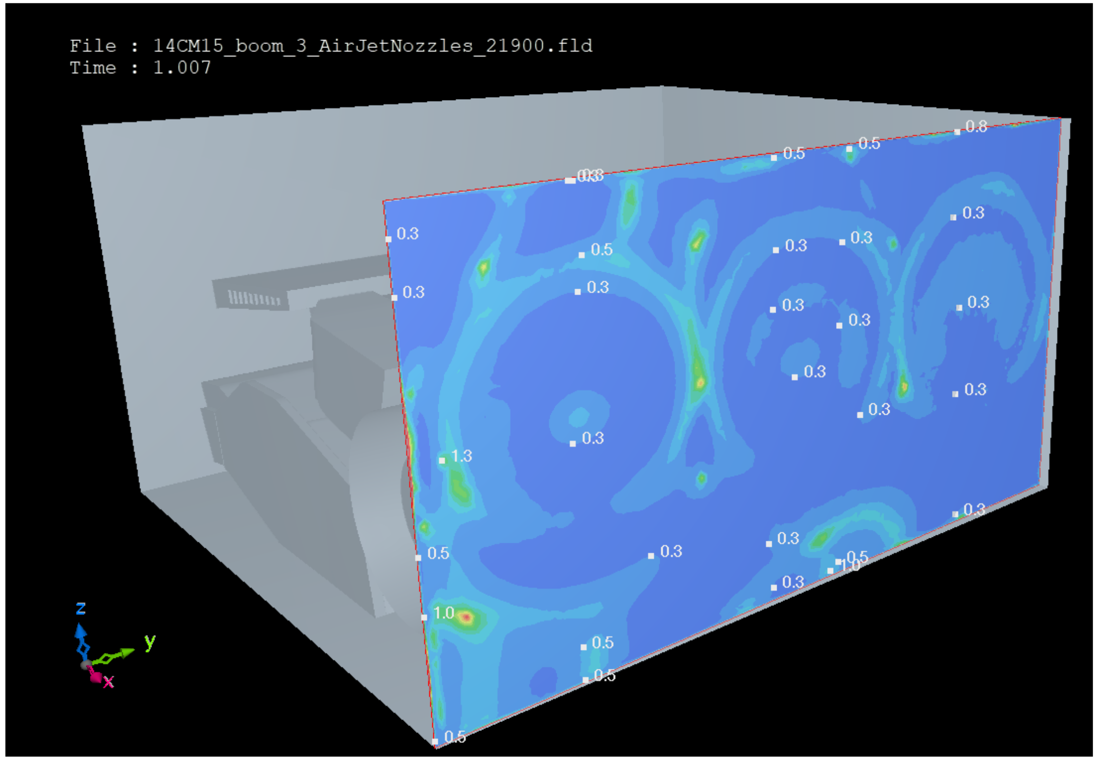
$$u' = \sqrt{\frac{2}{3}k}$$

- Despite the obvious changes in Tu, caused by the air jets, the maximal values at the face are not exceeding 1% which indicates very low turbulence intensity.



Study of Air Jet System Mounted on CM

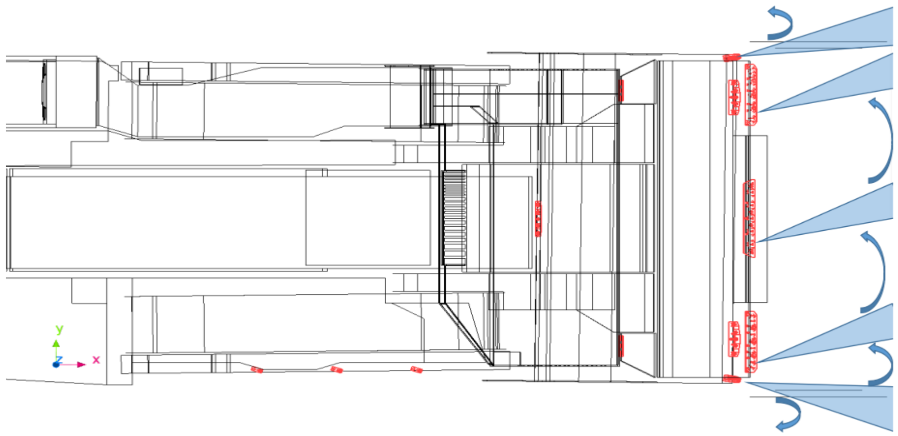




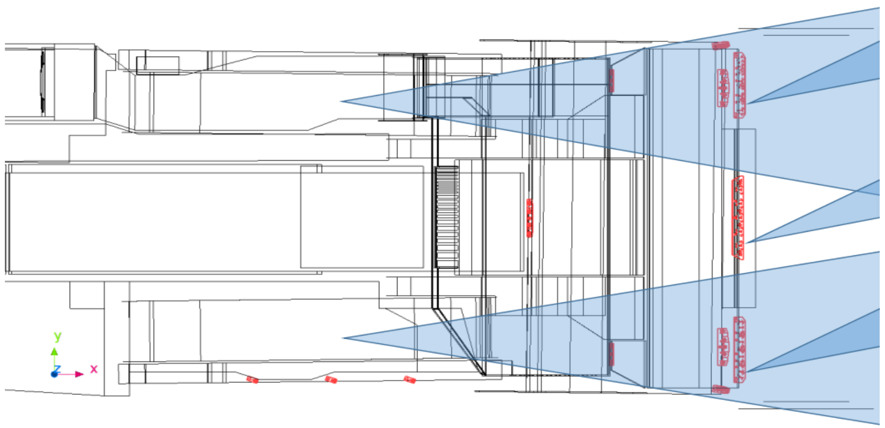
Turbulence Intensity in 1 sec of Air Jet Development

Study of Air Jet System Mounted on CM

- Detailed airflow analysis demonstrated, that the major portion of fresh air reaching the immediate face zone is being delivered above the CM's boom, while a significant part of the fresh air is collected by the scrubber before reaching the face.
- The corners of the face may not be well covered by the strait air jets.
- In this regards, changes in the air jet layout were proposed to improve the face ventilation efficiency.



Proposed Air Pet Layouts



Study of Air Jet System Mounted on CM

In-Mine Measurements

In-Mine Measurements

- The measurement has been conducted in a safe area during a maintenance shift usig line curtain to simulate a face.
- the nozzles were connected connected to a compressor mounted at the back right board of the CM with a hose. Air Jet nozzles type H1/4U-SS030 were implemented.
- Series of measurement of the air quantity produced by the air jet nozzles with Pitot tube using PVC tube with has been performed .
- The measured velocity pressure was Pv = 30 to 39 Pa.
- The air velocity inside of the PVC tube has been estimated in a range of 1,500 - 1,800 ft/min given the air quantity of 7.5 - 8.6 cfm per nozzle
- Additional air velocity measurement has been conducted with a Hot Wire Anemometer placed at the central axis of the nozzle, 27” away of the orifice. The measured air velocity was 1,732 ft/min.

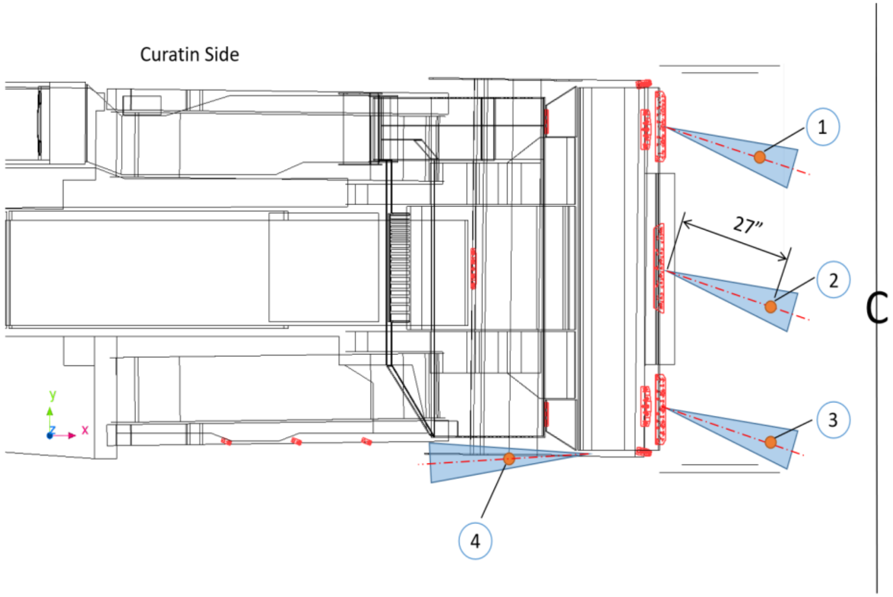


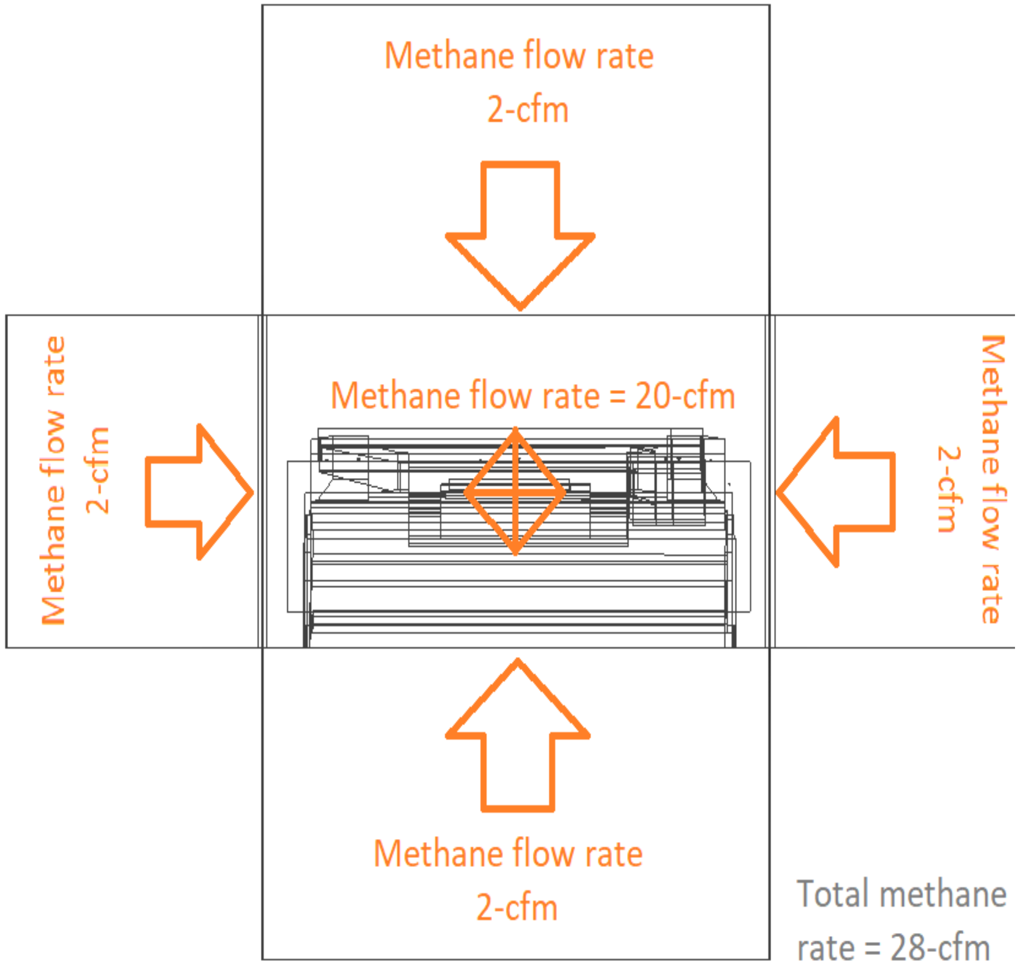
Table 1. Average air jet axial velocities

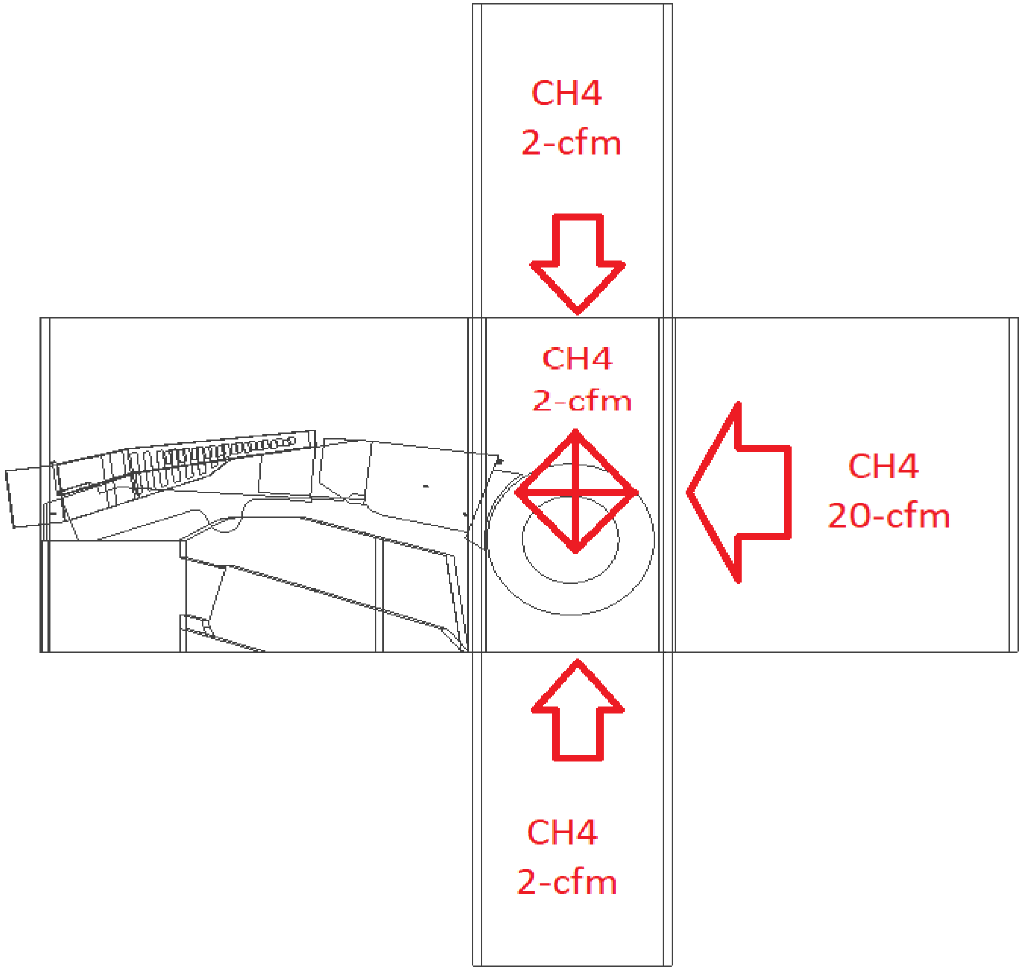
Air Jet Nozles # H1/4U-SS030	Three Nozzles 0.5” hose Average Air Velocity ft/min	Four Nozzles 0.5” hose Average Air Velocity ft/min	Four Nozzles 1” hose Average Air Velocity ft/min
Front (1, 2, 3)	1,861	1,585	1,732
Return (4)	N/A	1,657	

Study of methane Dilution Capacity of The Air Jet System

Study of Methane Dilution Capacity of the Air Jet System

Model Setup



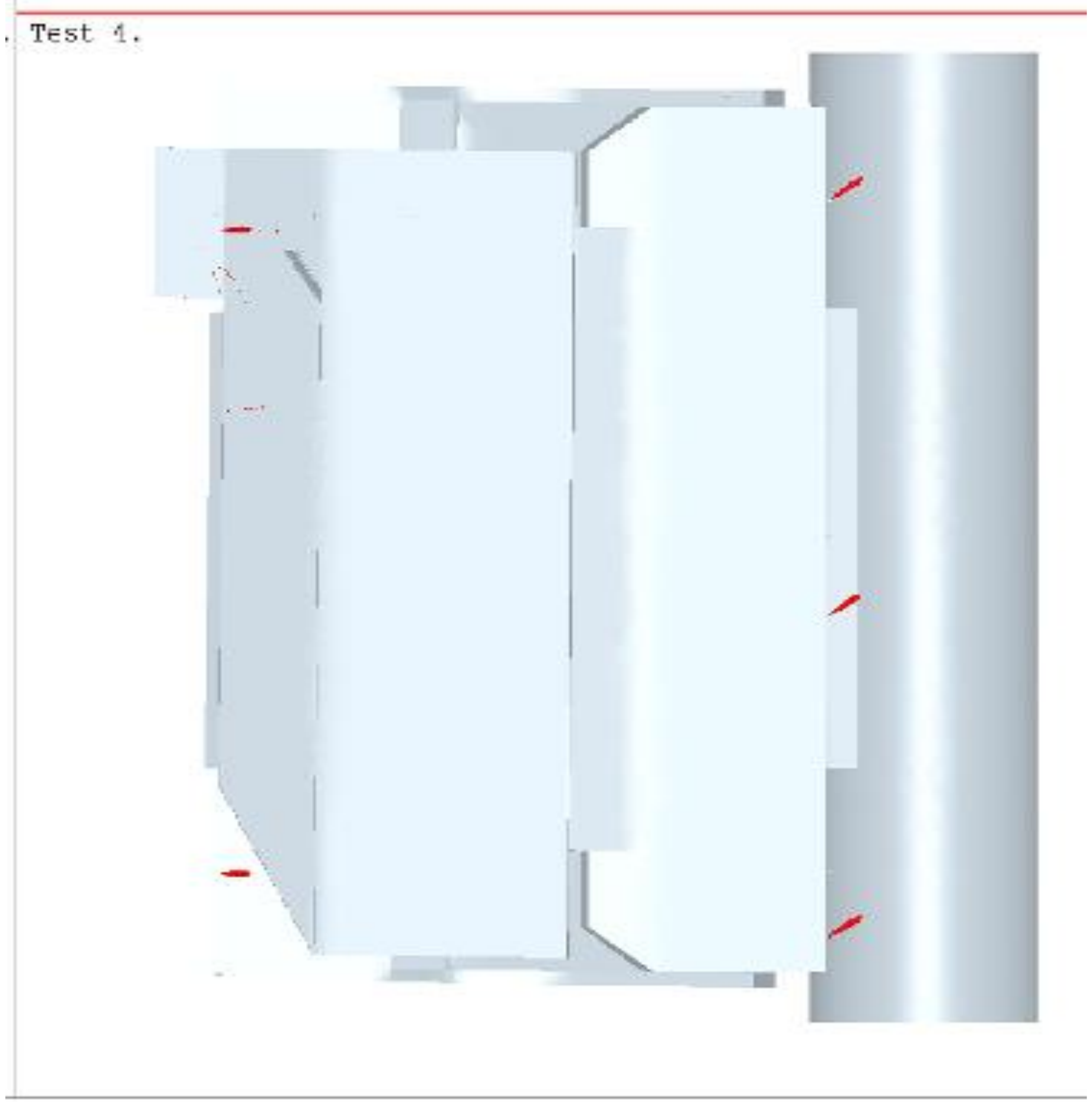


Total methane rate = 28-cfm

Study of Methane Dilution Capacity of the Air Jet System

Model Setup of Test 4

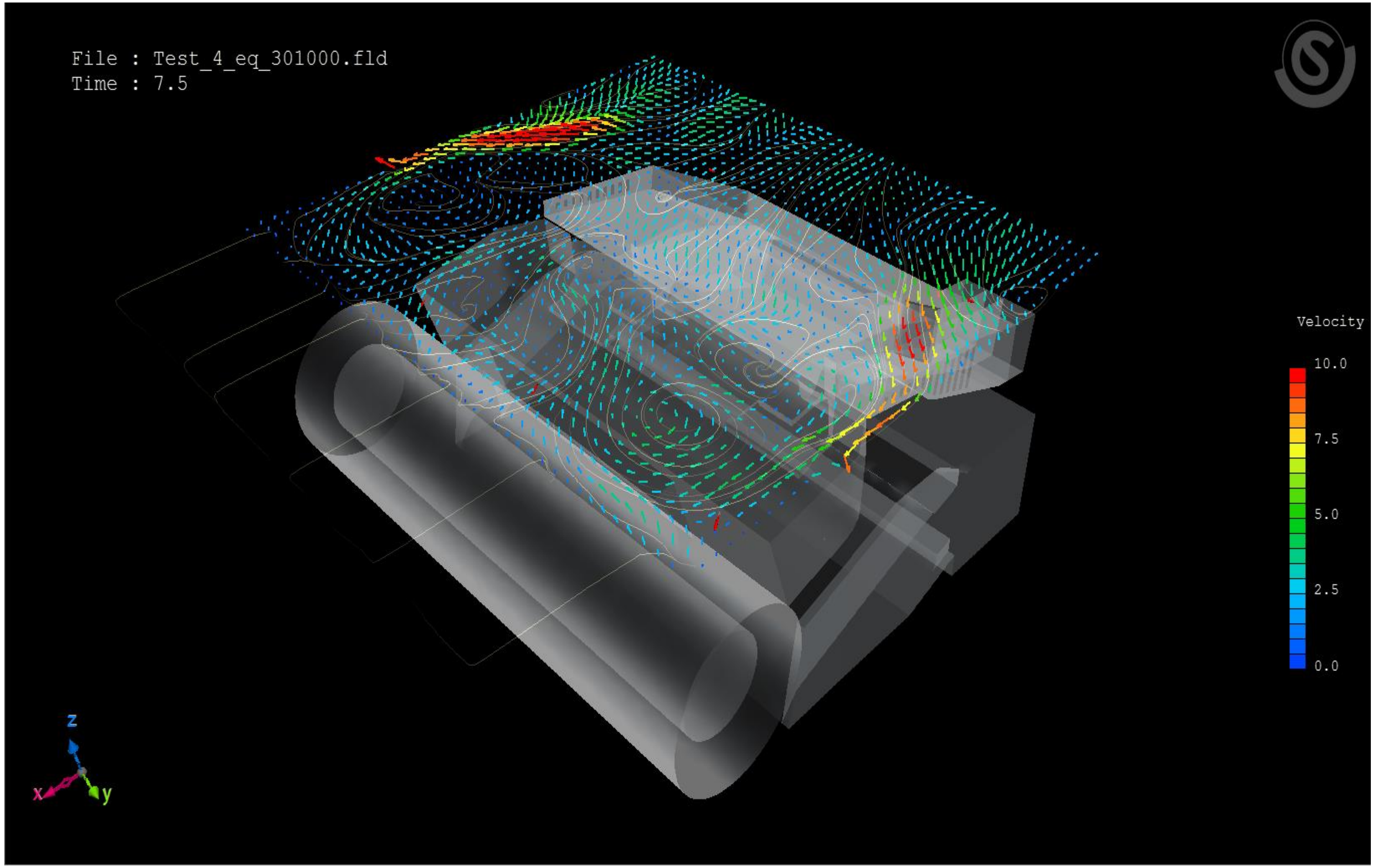
- The Air Jets configuration includes five nozzles, three front nozzles angled to the return side and two nozzles positioned on top of the boom, behind the scrubber inlet.
- Nozzle’s d=0.118-in (3 mm), initial pressure of Pi=10 psi, and entrainment air quantity Qn=4.2-cfm



Study of Methane Dilution Capacity of the Air Jet System

Test 4 CFD Results

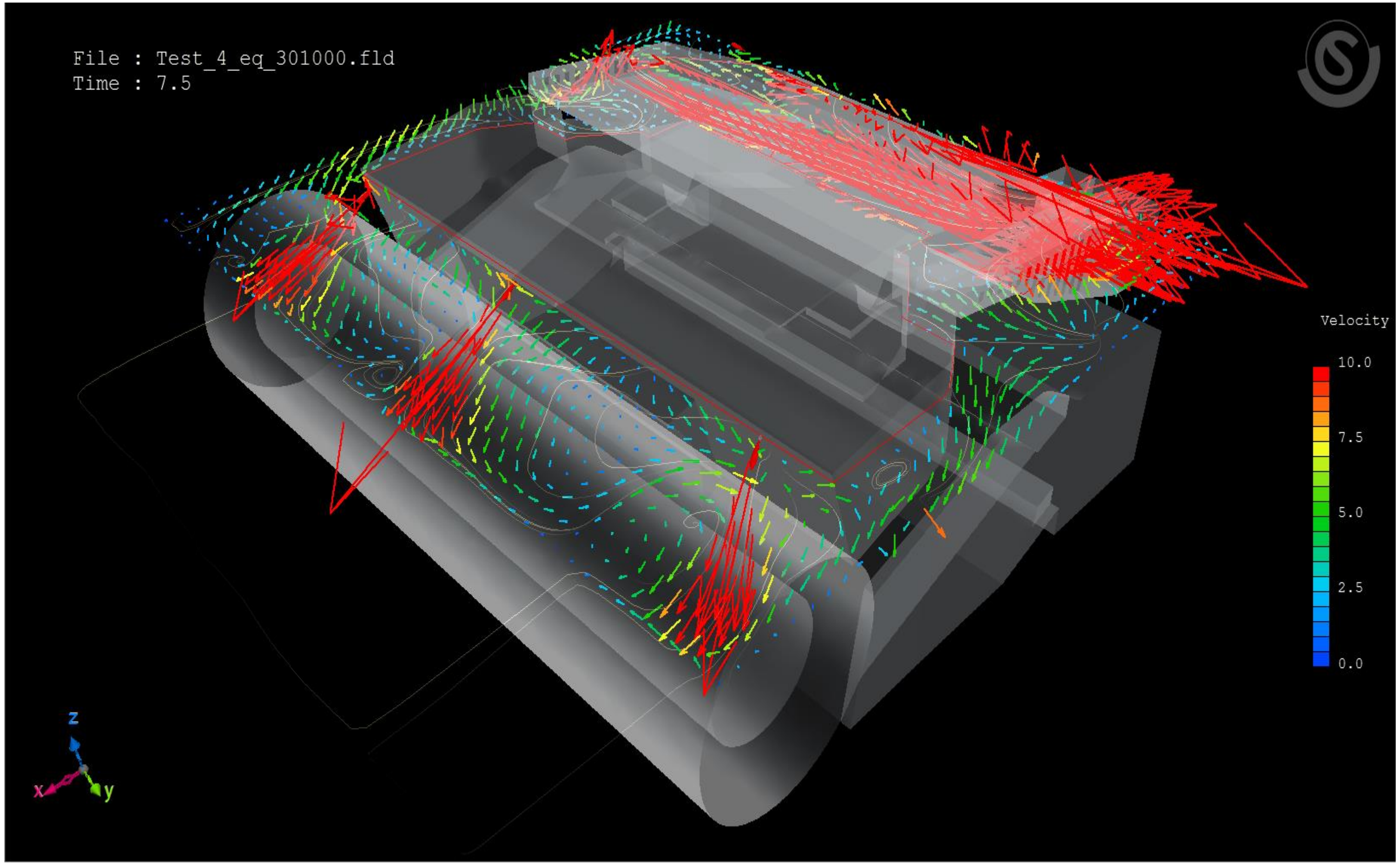
- The simulation showed that the rear couple of nozzles have positive effect on the flow along the roof, however the air jet high velocity cores does not reach the face.



Study of Methane Dilution Capacity of the Air Jet System

Test 4 CFD Results

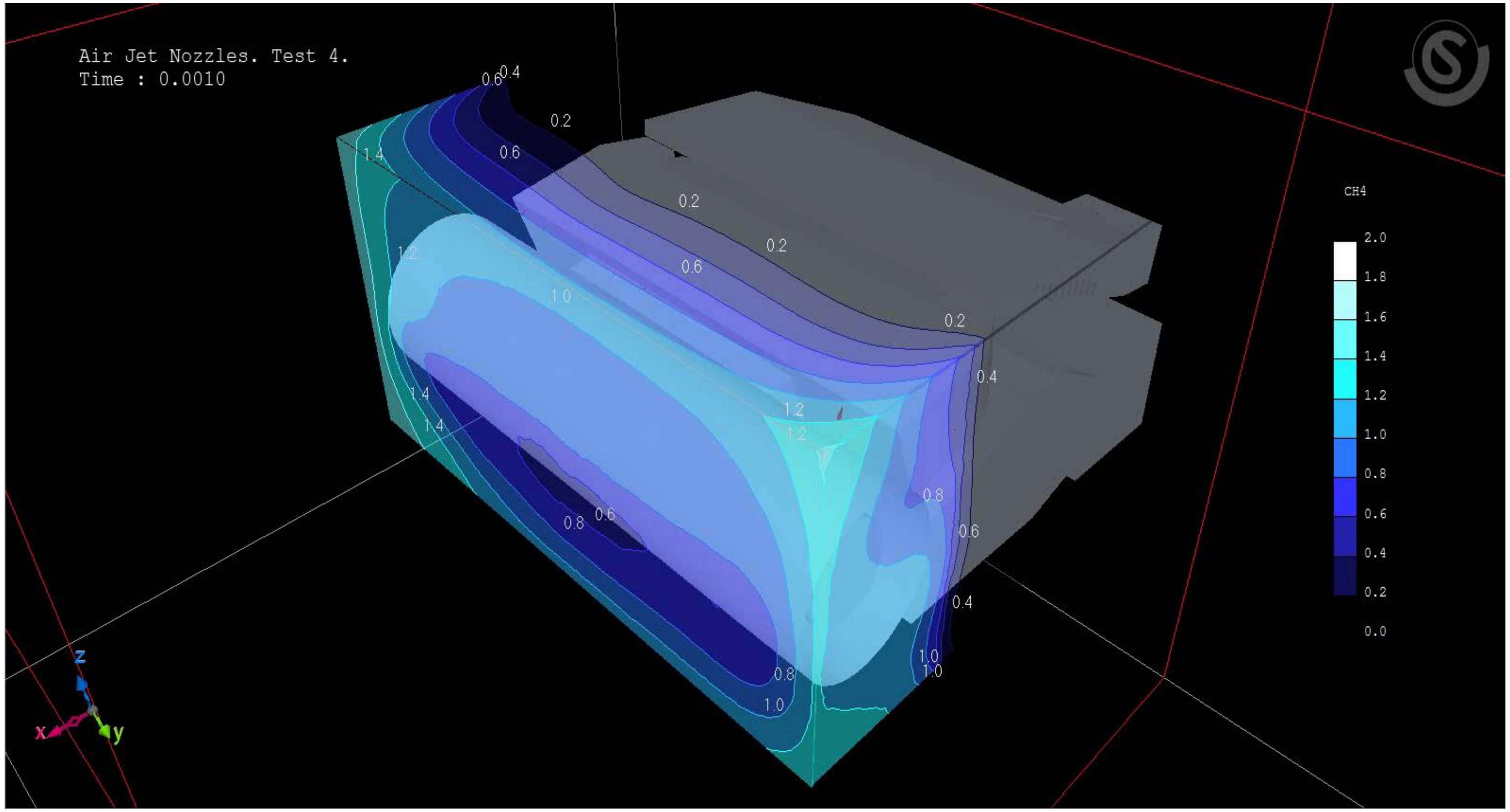
- The air jet created by the front three nozzles reaches the face with maximal air velocity of 8 ft/s.
- The average magnitude of the air velocity at the face was computed to 2.23 ft/s using integration along the face area.



Study of Methane Dilution Capacity of the Air Jet System

Test 4 CFD Results

- The average methane concentration at the face drops from 1.0% to 0.5% for 7.5 sec.
- The highest values of 1.4%-1.6% were located in thin spots around the curtain-side ridge.
- The average methane concentration at the face in the end of the simulation was calculated to 0.473%.



Study of Methane Dilution Capacity of the Air Jet System

Comparisons and Conclussions

- The test layouts have shown very good performance in methane dilution.
- The simulation results have shown that the front three air jet nozzles have the major impact on methane ventilation at the immediate face zone.
- To complete the analysis, study of the desired Air Jet layouts together with the water spray system is needed, as well as risk evaluation in case of increased methane liberation.

Parameter	Test 3 Two intake-return plus three front air-jets	Test 4 Two top nozzles plus three front air-jets	Test 5 Two front blocking nozzles plus three front air-jets	Test 6 Sprays only
Average Air Velocity, ft/sec	2.33	2.23	2.22	4.1
Turbulence Intensity, %	48.51	36.24	40.53	68.27
Average Methane Concentration, %	0.330	0.473	0.397	0.501

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A Large Underground Stone Mine Ventilation Case Study

Turbulence Analytics

A Large Underground Stone Mine Ventilation Case Study

Typical Features

- Typical face areas are 40 ft wide by 25 ft high 14 ft pulled with each blast.
- Pillars are commonly set on 100 ft × 100 ft centers with 75% extraction.
- This equates to over 1,000 tons of stone per production blast based on standard ore density.
- Benching is common in thicker beds with heights of 100 ft having been recorded in mines after successive benching.

Photo by aggman.com

A Large Underground Stone Mine Ventilation Case Study

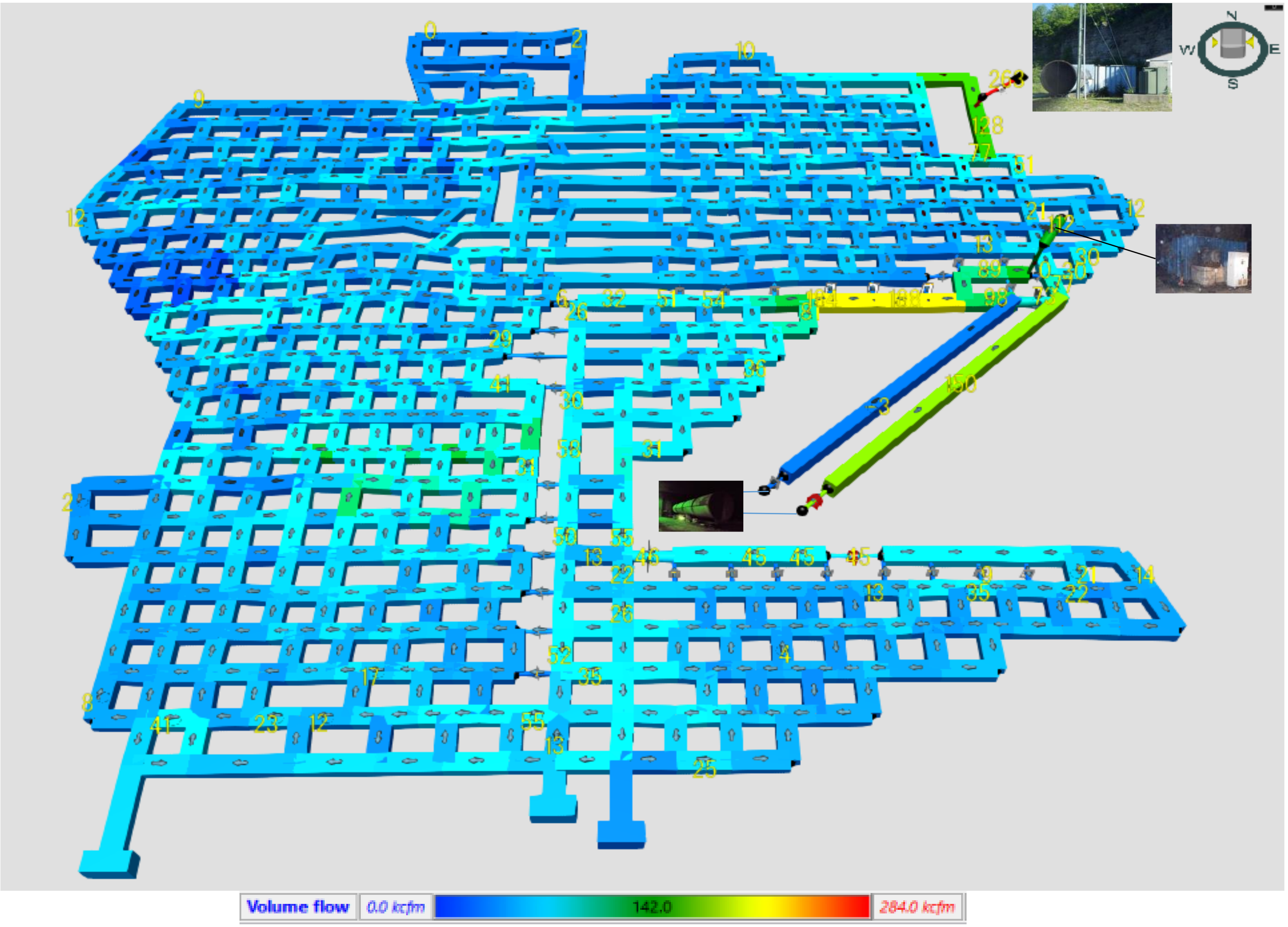
Typical Features

- A 1,000 ft long drift that is 40 ft wide by 25 ft high, with a k factor of 0.0130 kg/m^3 (6.99×10^{-9} $lbf{\cdot}min^2/ft^4$) could move 750,000 cfm of air at a static pressure loss of 0.1 in w.g. (25 Pa) [*Head, R, Aggregates Manager, pp 17-19, April 2001*].
- The remainder of the workings, which have an even lower resistance in most cases, can be ignored in the calculations.
- Shock losses, air temperature differences, and even the wind load can all have a large impact on ventilation performance due to the low system resistance.

A Large Underground Stone Mine Ventilation Case Study

Practical Example

- The mine is a multilevel underground operation for crushed stone and agriculture lime and extracting about 650,000 tons limestone per year.
- The upper level is accessed by a surface ramp and contains the major underground storage, the underground crusher and other facilities.
- The lower level is accessed from upper level via a double decline and contains production sections only.



Lower Level Mine Network Model (2022)
Powered by VUMA Network Software

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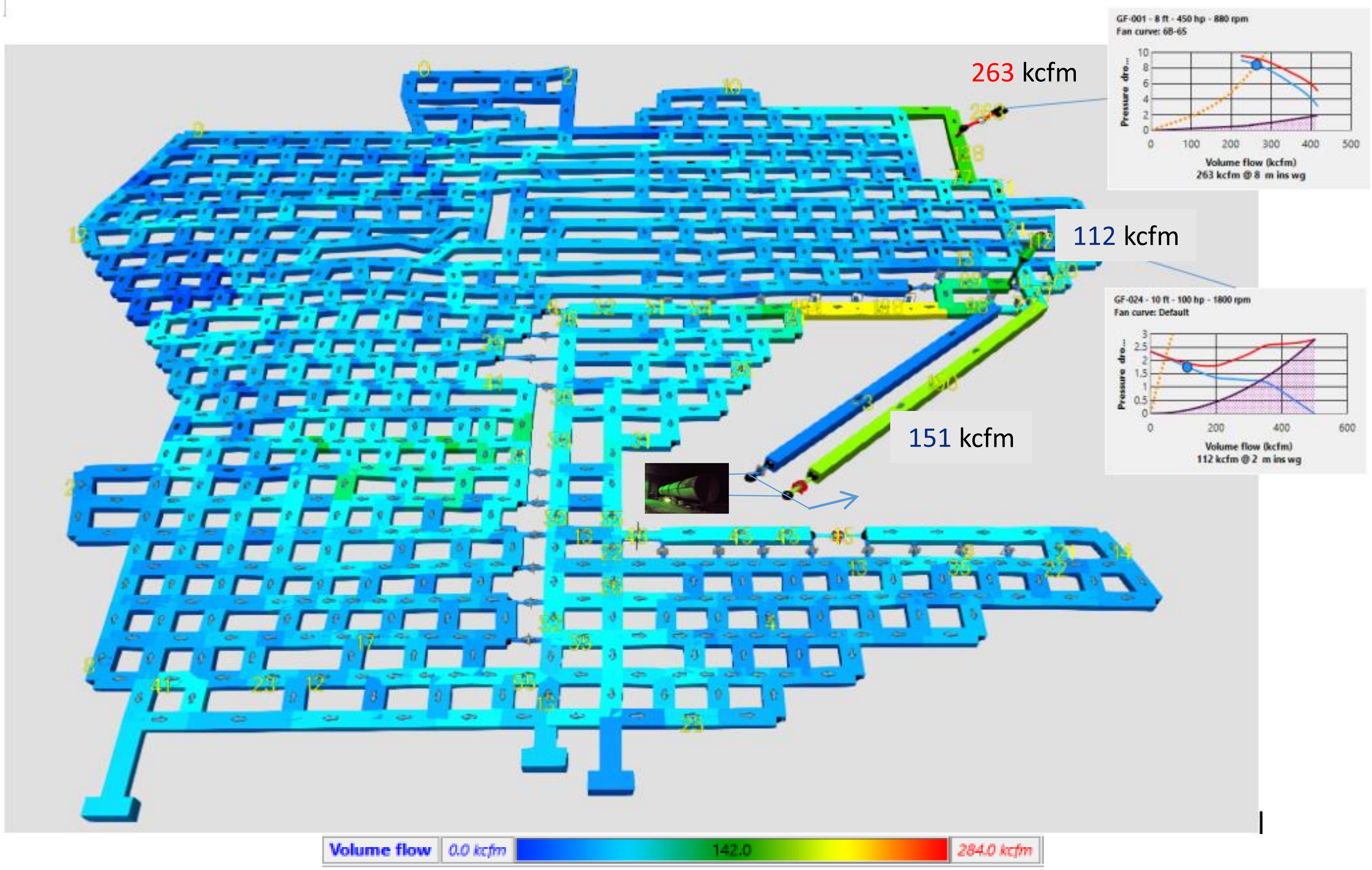
Ventilation Parameters

- The mine is ventilated by two interconnected push-pull ventilation systems serving the upper and lower mine levels respectively.
- Total flow ventilating the Lower level mine was estimated to 263,000 cfm or 20,000 lb/min.
- Average ambient conditions:
  - Temp = 63 °F,
  - Air density = 0.075 lb/ft^3, and
  - Bar. pressure = 1,027 hPa



Lower Level Mine Network Model

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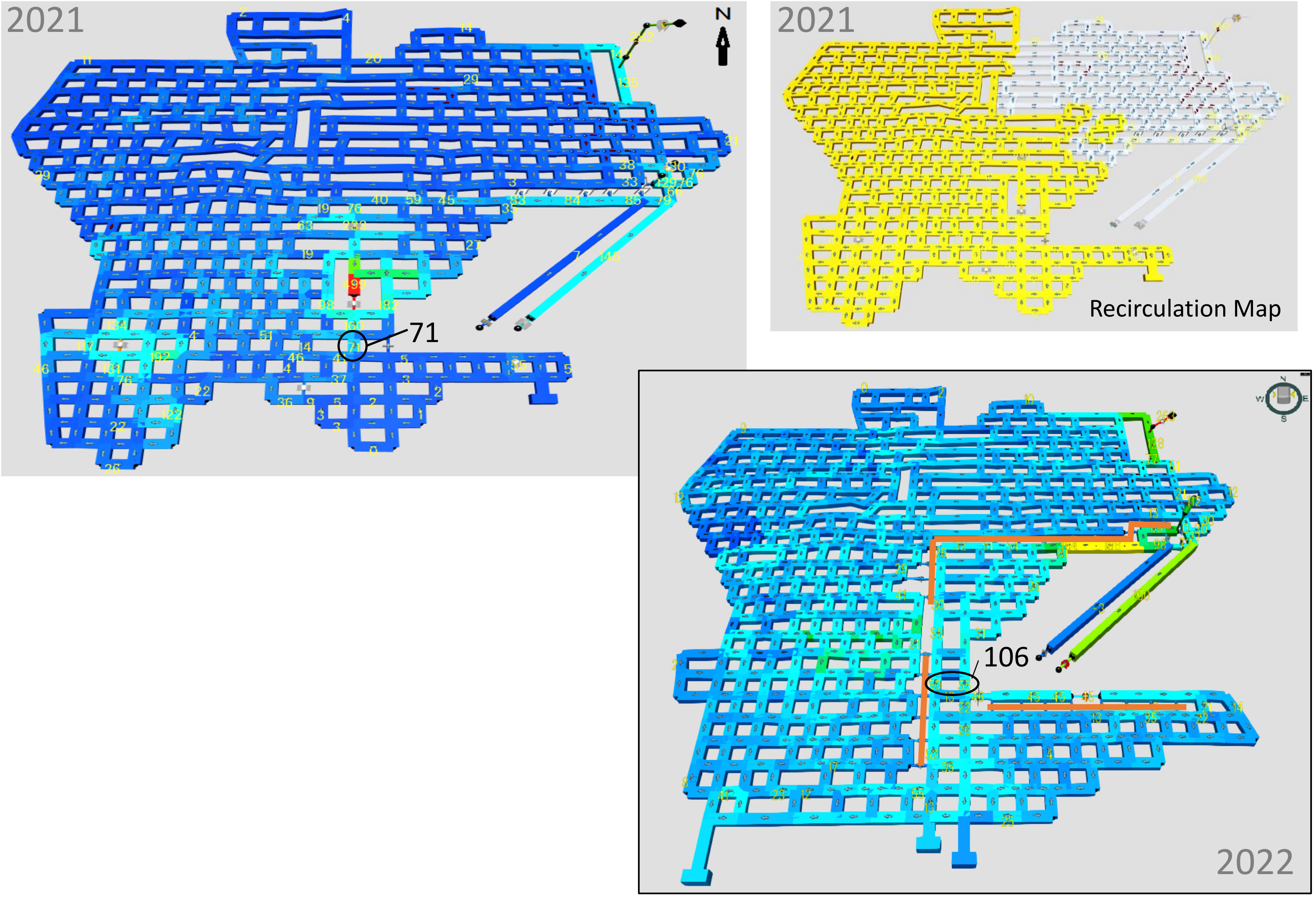
Ventilation Development

The previews state (2021) of mine ventilation characterized with significant flow recirculations, flow reversals and decresing air quantities to the soutern working sections.

The current state (2022) of the mine ventilation have been achieved after number of improvements including:

- Building stopping lines
- Re-organizing the auxiliary/booster fan power.
- Transition of the mine development layout to Arrow-shape.



Lower Level Mine Network Models (2021-2022)

A Large Underground Stone Mine Ventilation Case Study

Blast Clearance Analysis

- Since 1998, there have been 57 documented incidents from blasting sides related to CO poisoning in the United states and Canada, including suspected or medicaly verified cases (Adhikari et all, Mining Engineering, pp 54-55, August 2022).
- In 2013, 20 miners were exposed to CO at Revenue-Virginius Mine in Clolarodo, including two fatalities (MSHA report, 2013).
- Time dependent computer simulation were performed to compute blast clearance development of CO, NOx and Dust generated by the explosives, 12 hours after blasting.

Input data:

Explosive: ANFO (on site mix)

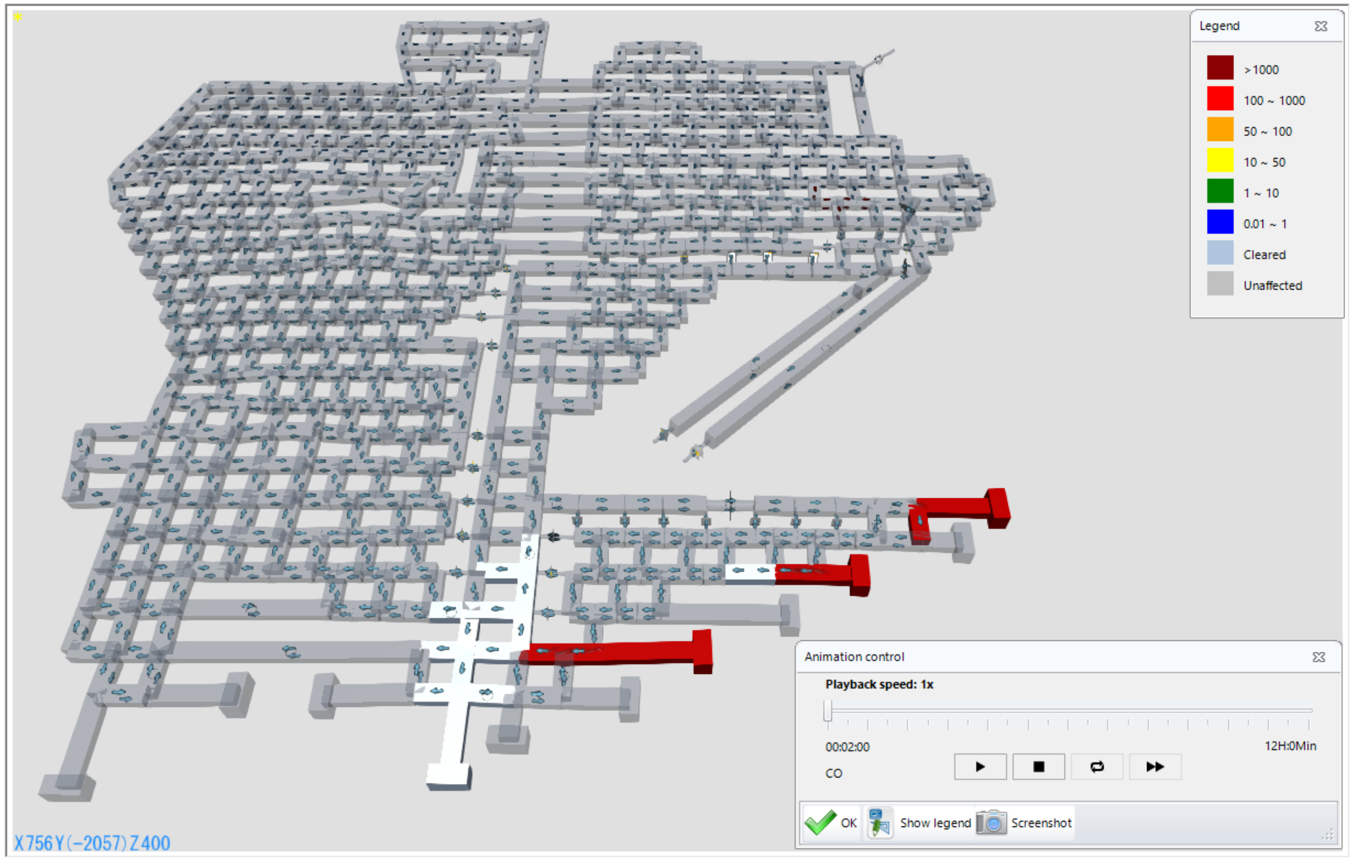
Number of development ends: 3

Explosive used per development end: 600 lb

CO rate = 165.3 lb/t

NOx rate = 38.9 lb/t

Dust rate = 2.4 lb/t



Lower Level Mine Blast Clearnce Network Model

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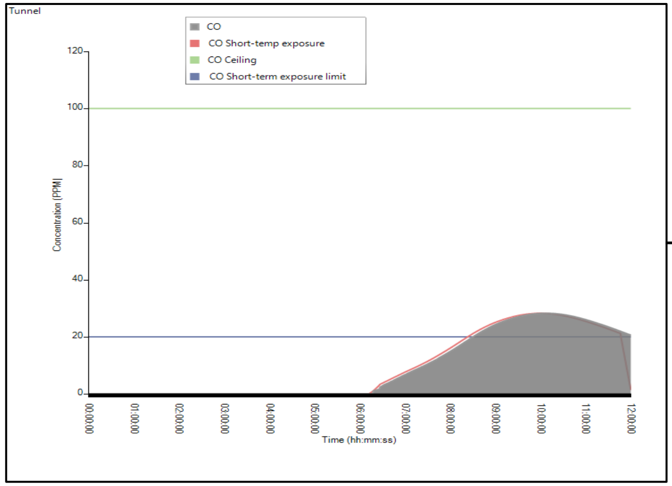
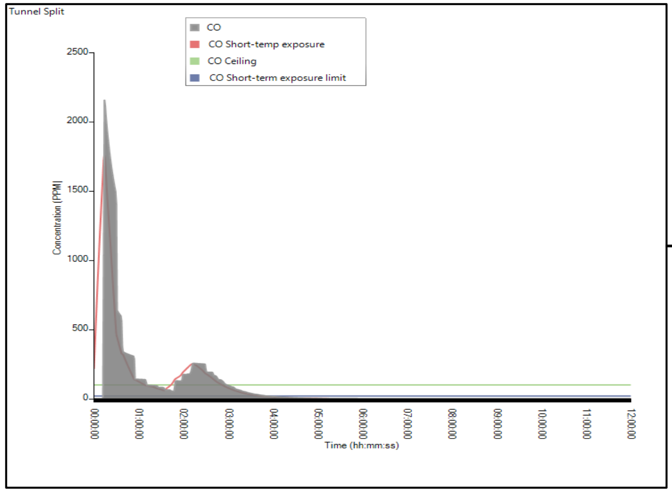
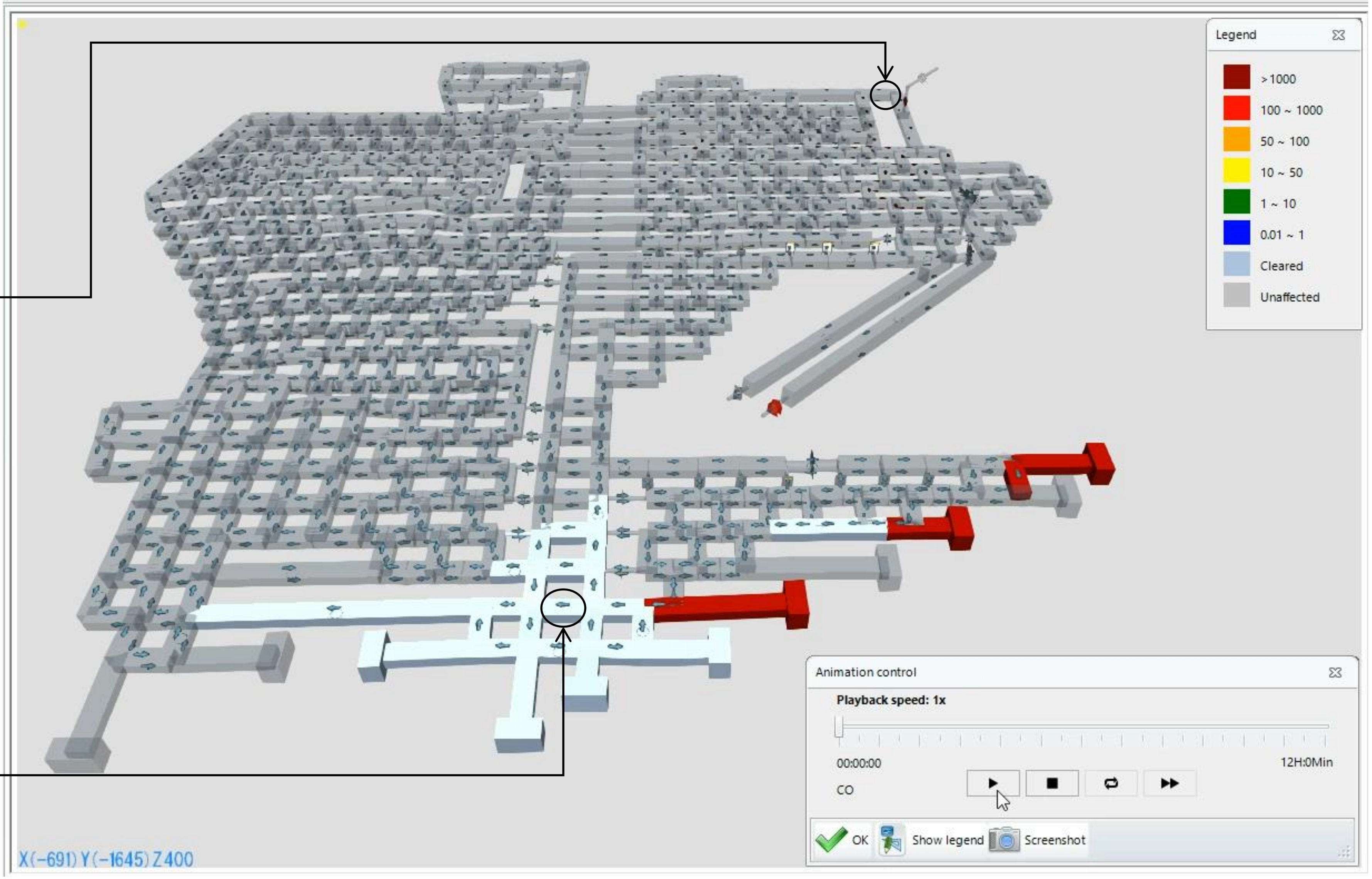
Blast Clearance Analysis







CO blast clearance 12 hours after the blasting

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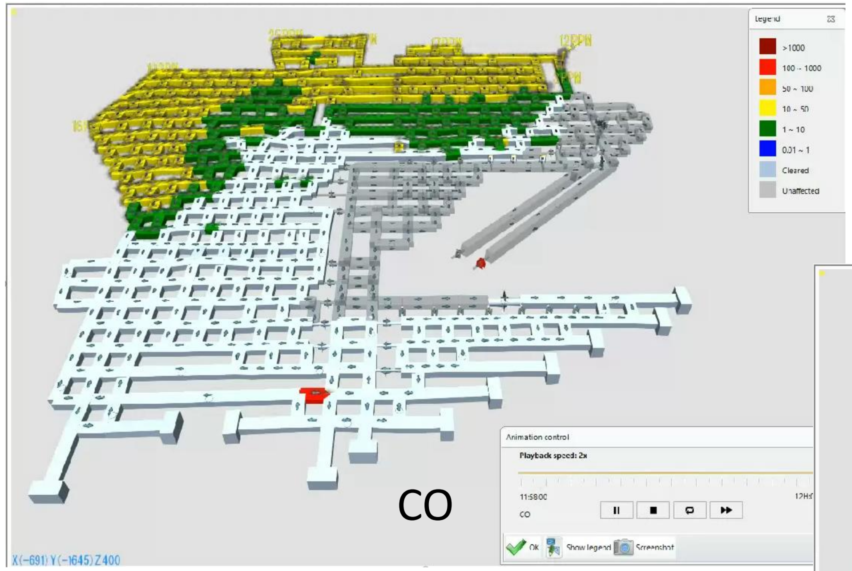
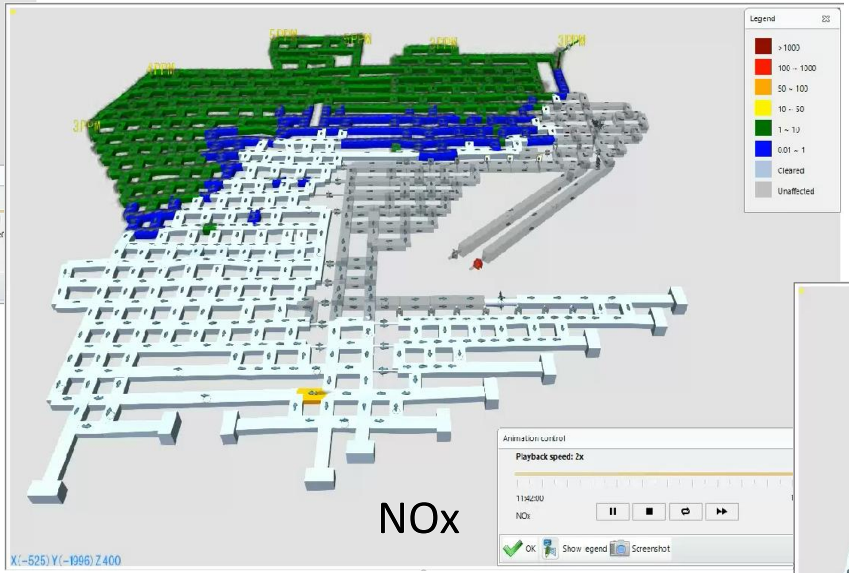
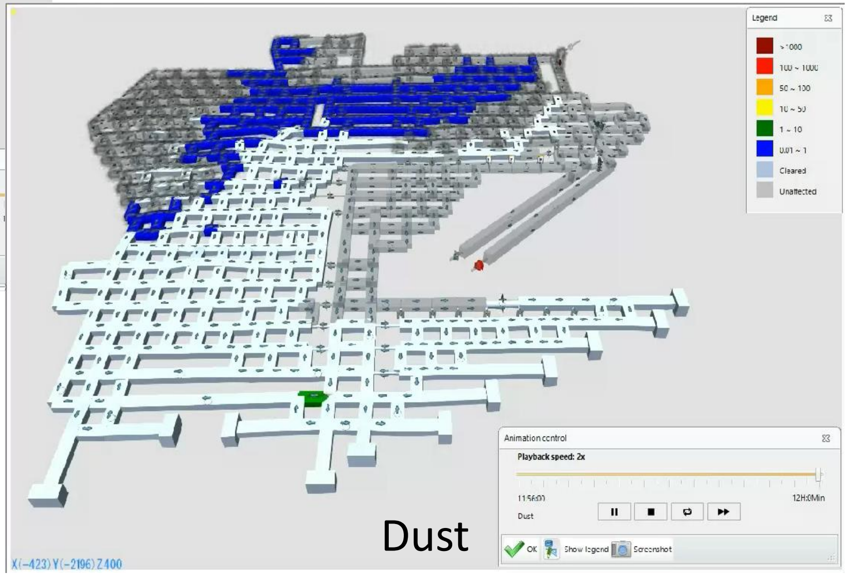
Blast Clearance Analysis







Blast clearance 12 hours after the blasting

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The work continue with:

- Validation of the blast clearance model v/s in-mine data
- Emergency main fan down scenario
- New ventilantion shaft design scenarios
- Diesel Particulate Matter (PDM) distribution analysis
- Simulation of Undrground fire cases and tracing of safety escape route

Thank You!