JENSEN HUGHES

Feasibility Analysis and FDS Modelling of Water Mist Fire Suppression Systems for the Protection of Aircraft Hangars

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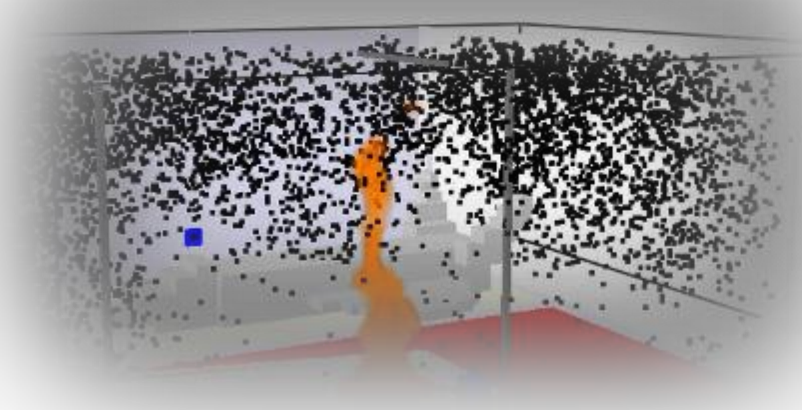
Presentation Overview

Outline

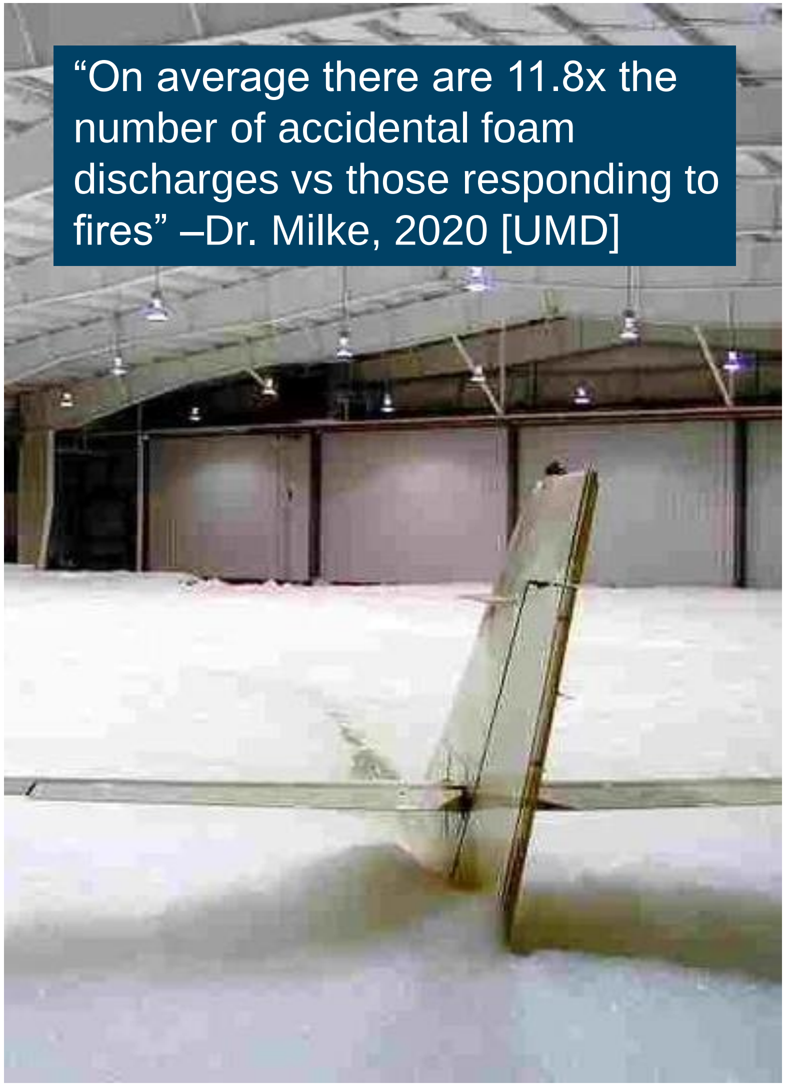
+ Motivation / Project Background
+ COTS Water Mist Literature Review Results
+ FDS Models
  - Engineering Configuration
  - FDS Inputs
  - Validation Studies
  - Results



U.S. Air Force & UMD Research Project

Research Motivation

+ Risks associated with per-and polyfluoroalkyl substances (PFAS) containing aqueous film forming foams (AFFF) [NFPA 72]
  - Toxicity
  - Biodegradability
  - Persistence
  - Persistence in wastewater treatment plants
  - Nutrient loading



COTS Literature Review Summary / Results

Identify all COTS Water Mist System → **Literature Review Criteria** → **Down Selection / Final Recommendation**

- 15 COTS water mist manufacturers identified for evaluation
  - Low pressure (P ≤ 12 bar)
  - Intermediate pressure (12 bar <P ≤ 34 bar)
  - High pressure (P > 34 bar)
  - Hybrid systems (inert gas + water mist)

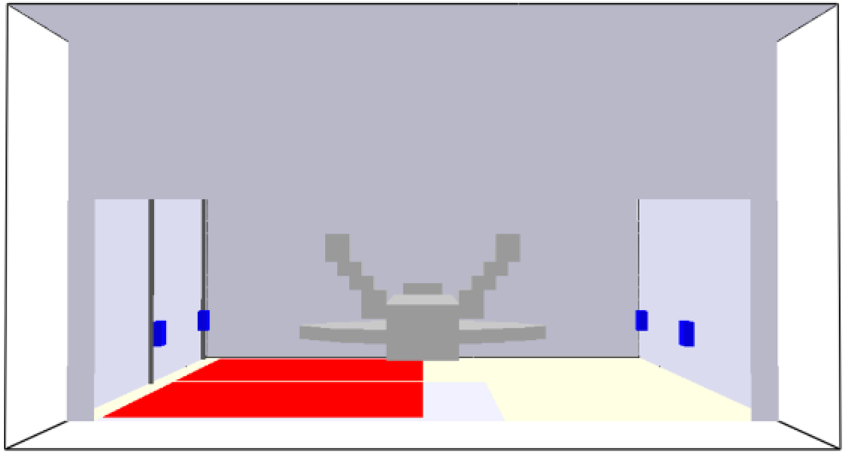
- Marketed applications
- Industry installations
- Test results for class B fires
- Relevant approvals (FM &IMO)
- Public literature water mist characteristics

- 8 manufacturers initially dismissed
- 7 manufacturers identified as potentially successful
- 2 manufacturers (3 nozzles) identified for Phase II
  - Nozzle A: Low pressure ceiling nozzle
  - Nozzle B: Low pressure floor nozzle
  - Nozzle C: High pressure ceiling nozzle

FDS Background / Model Overview

FDS Overview

+ Computational Fluid Dynamic (CFD) model of fire-driven fluid flow
  - Solves modified Navier Stokes equations
  - Low mach number approximation
  - Large eddy simulation (LES)



Engineering Configuration

+ Mock F-35 aircraft hangar
  - Overall dimensions: 26 m x 26 m x 12 m
  - Hangar door: 24 m x 7 m
  - Aircraft: 11m (wingspan), 16 m (length), 2 m (fuselage height), 4 m (tail height)
+ JP-8 unconfined fuel spill
  - 12 m x 24 m (assumed trench system)
+ Electrical boxes and structural steel members
+ Water mist nozzle spacing based on manufacturer recommendations

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Fuel Model : JP-8 Jet Fuel unconfined spill

FDS Sub Models

+ Pyrolysis Model: *Liquid pyrolysis*
+ Combustion Model: *Infinitely fast, mixing controlled combustion*
+ Radiation Model: *Optically thin, specified radiative fraction*

FDS Inputs

Property	FDS Input Value
C_p, $[\frac{kJ}{kg*K}]$	RAMP T = 20, F = 2 T = 17-, F = 2.65
P, $[\frac{kg}{m^3}]$	780
k, $[\frac{W}{m*K}]$	RAMP T= 20, F= 0.115 T=170, F = 0.085
h_v, $[\frac{kJ}{kg}]$	350
χ_r	0.05
T_b, $[°C]$	190
Absorption Coefficient	301
Soot Yield	0.03

Lagrangian Particle Model: Nozzles

Required Inputs

+ K-factor
+ Operating Pressure
+ Offset Distance
+ Particles Per Second
+ Initial Velocity
+ Spray Angle
+ Droplet Size Distribution

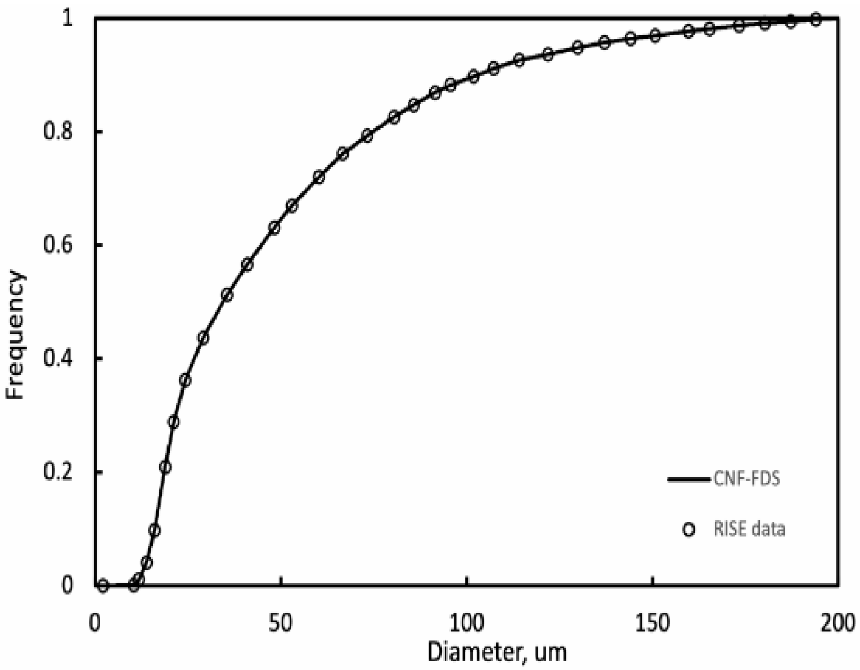
Rosin-Rammler Log-Normal

$$F_v(D) = \begin{cases} \frac{1}{\sqrt{2}\pi}\int_0^D \frac{1}{\sigma D'} exp(-\frac{\left[ln\left(\frac{D'}{D_{v,0.5}}\right)\right]^2}{2\sigma^2})dD' & (D \leq D_{v,0.5}) \\ 1 - exp(-0.693 * \left(\frac{D}{D_{v,0.5}}\right)^\gamma) & (D > D_{v,0.5}) \end{cases}$$

Nozzle Characteristic Validation Simulations

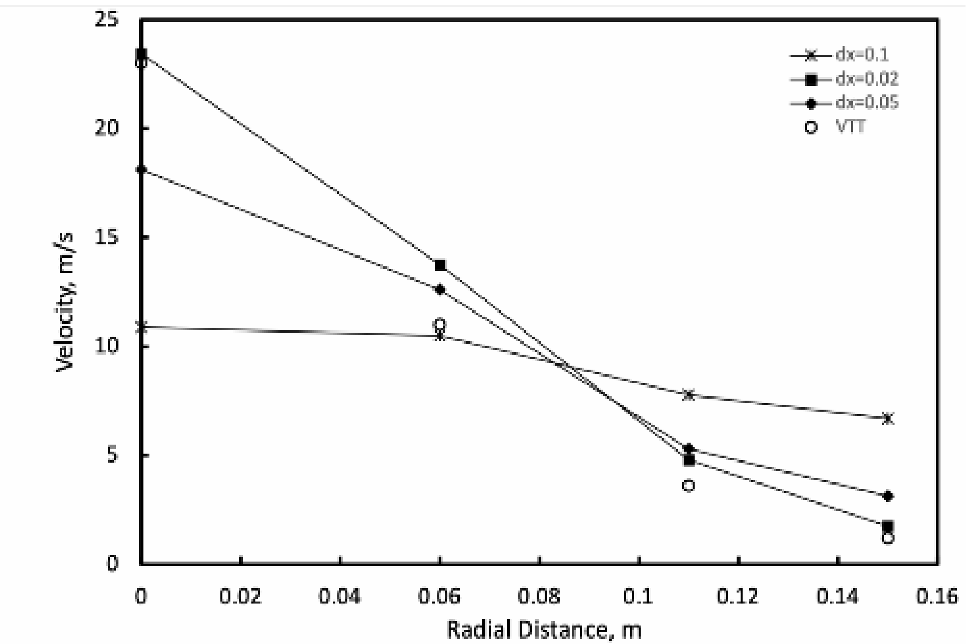
Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted

Nozzle A



Droplet Size Distribution
Frequency vs diameter [µm]

Nozzle C



Initial Velocity Validation Test
Initial Velocity [m/s] vs height [m]

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Nozzle A, B, & C Characteristics

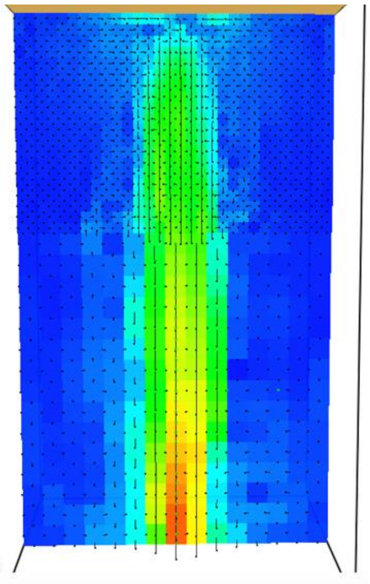
Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted

Parameter	Nozzle A	Nozzle B		Nozzle C	
		Center Nozzle	Perimeter Nozzle	Center Nozzle	Perimeter Nozzle
K-factor [$\frac{L}{min*bar^{1/2}}$]	5.6	10	10	0.433	0.433
P [bar]	16	8	8	70	70
V_0 [m/s]		35	20	118	118
ϕ [degrees]	80	60	60	24	24
Nozzle Orientation [degrees]		-	45	-	30
Droplet Size Distribution: D_{v50} [µm]	User specified (prev slide)	200	200	79	79
Droplet Size Distribution: γ		2	2	2.26	2.26
Droplet Size Distribution: σ		0.58	0.58	0.5	0.5
r_0 [m]	0.3	0.1	0.1	0.1	0.1

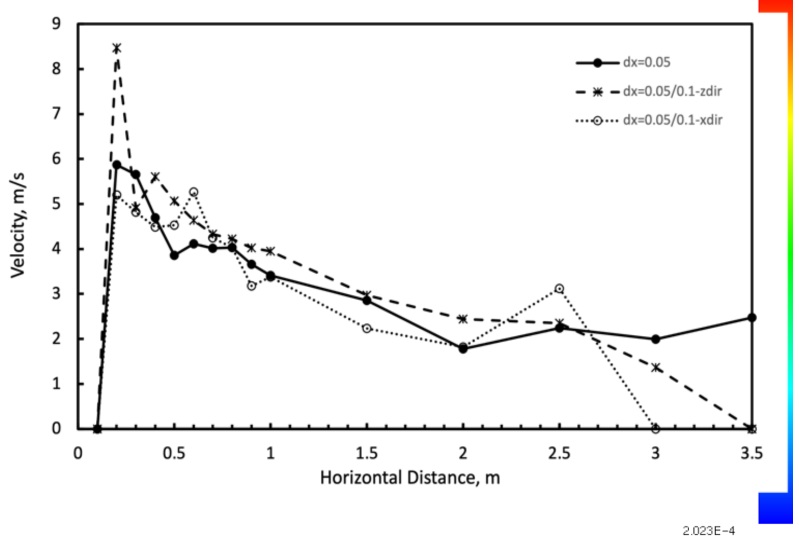
Grid Analysis & Selection

Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted

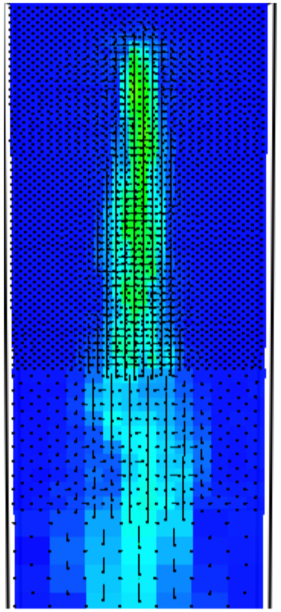
Nozzle A



Nozzle B



Nozzle C



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Simulated Scenarios

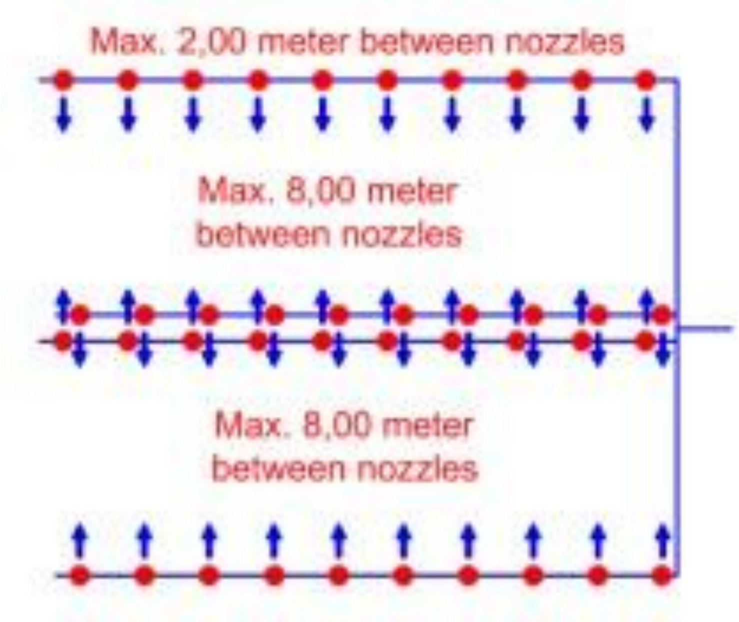
Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted

Activation Time	Center Ignition Source 30[1] sec	Center Ignition Source 50[2] sec	Side Ignition Source 30[1] sec	Side Ignition Source 50[2] sec
Nozzle A	A.1	A.2		
Nozzle B	B.1 & B.3[3]		B.2.a	B.2.b
Nozzle C	C.1	C.2		

[1]based on hand calculation estimates for flame detection

[2]based on DoD required activation time

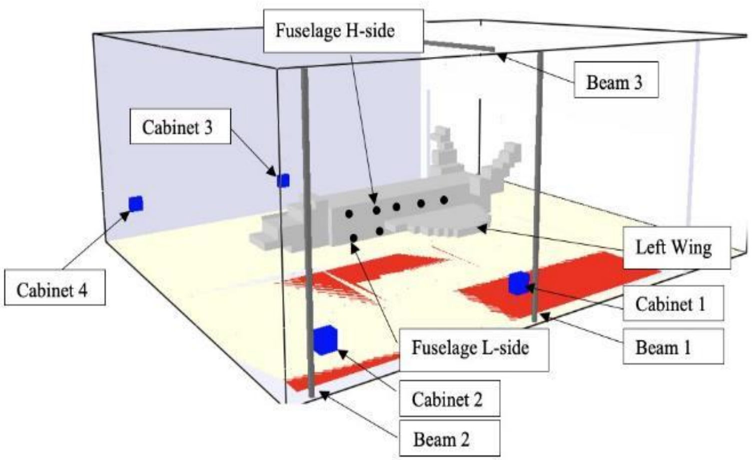
[3]Nozzle A and Nozzle B in hangar

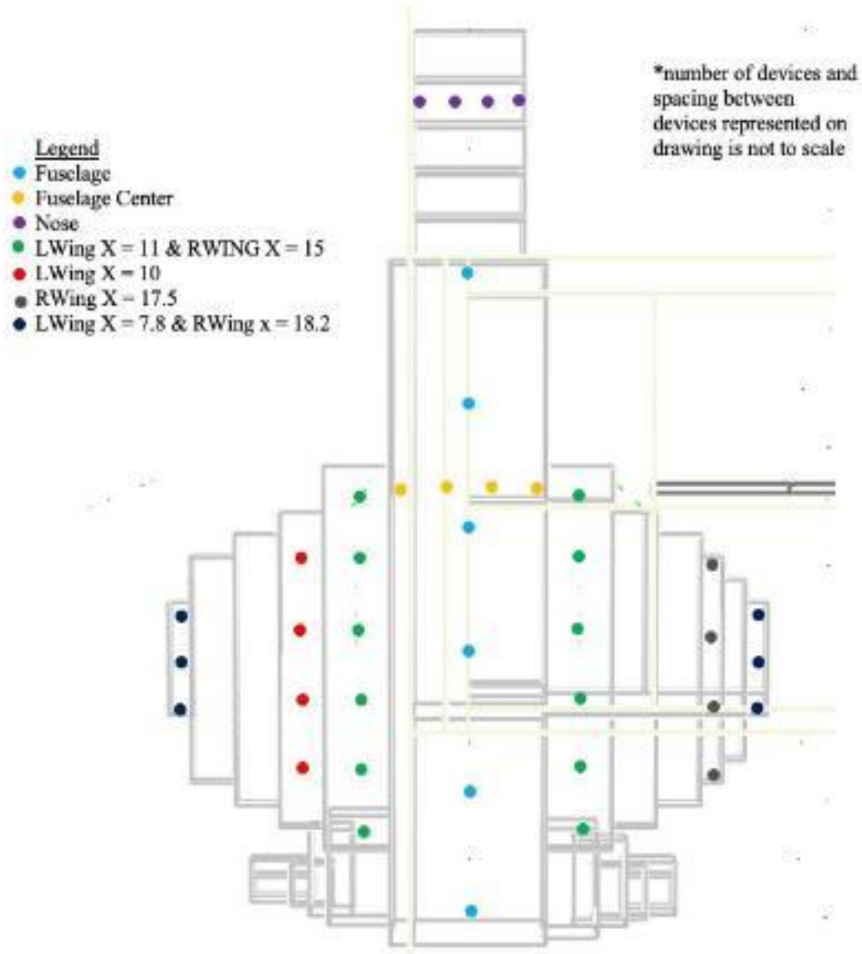


Results Guide

Performance Criteria

- Structural Steel members < 450 ºC
  Critical Heat Flux for Delamination
  - 15 kW/m^2 → 129 seconds
  - 25 kW/m^2 → 74 seconds
  - 35 kW/m^2 → 51 seconds
- Control of Fire





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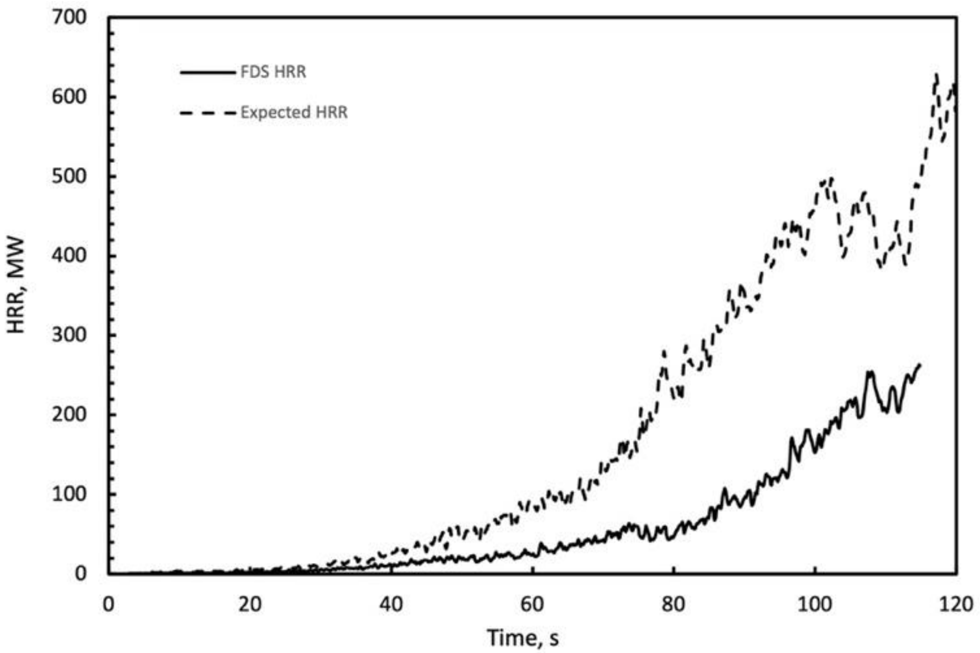
Simulation Results A.1

Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted



Performance Criteria

+ HRR is not controlled or suppressed
+ Max instantaneous structural steel temp: > 450 °C
+ Max incident heat flux to plane: > 35 kW/m^2

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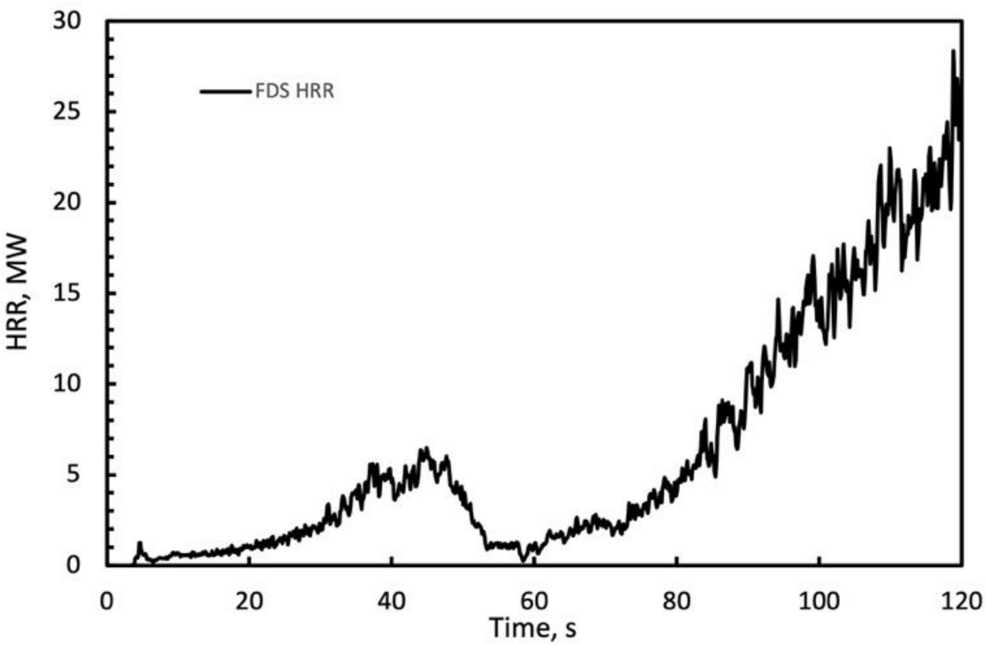
Simulation Results B.2 (Nozzle B)

Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted



Performance Criteria

+ Peak HRR: 25 MW + *(w/o suppression 100 MW at 60 seconds)*
+ Max instantaneous structural steel temp: < 400 °C
+ Max incident heat flux to plane: < 20 kW/m^2
  - Ignition source center of fuel spill

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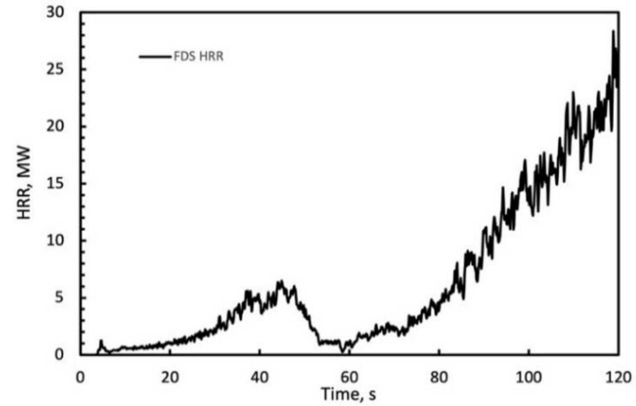
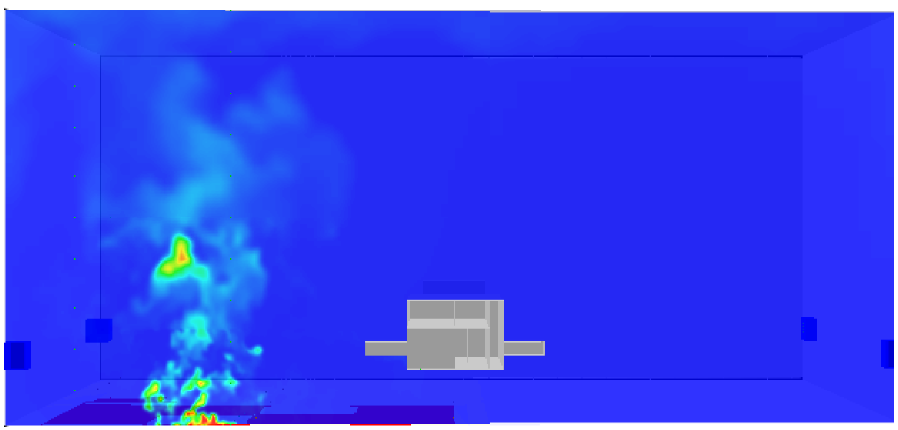
Simulation Results B.2 (Nozzle B)

Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted

Temperature at 40 and 120 seconds



t=40 sec



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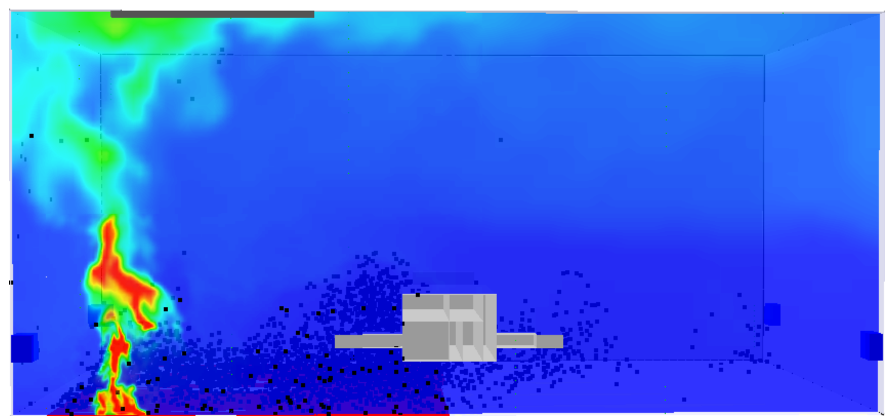

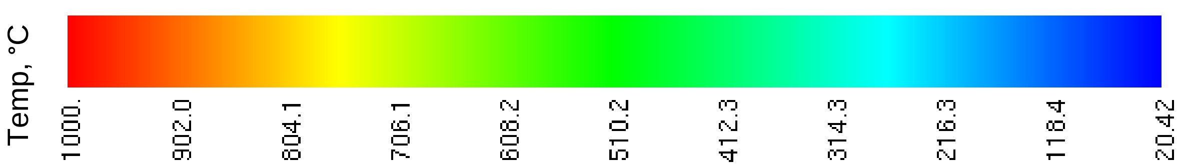

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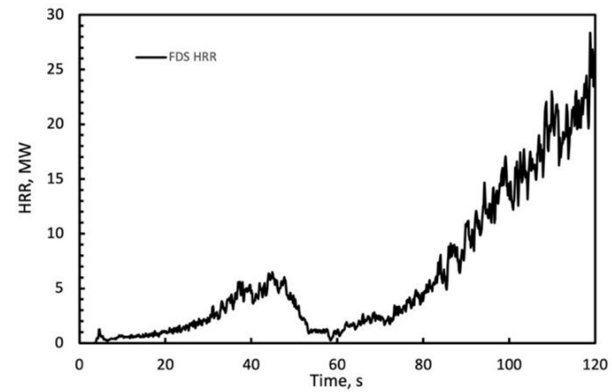
Simulation Results B.2 (Nozzle B)

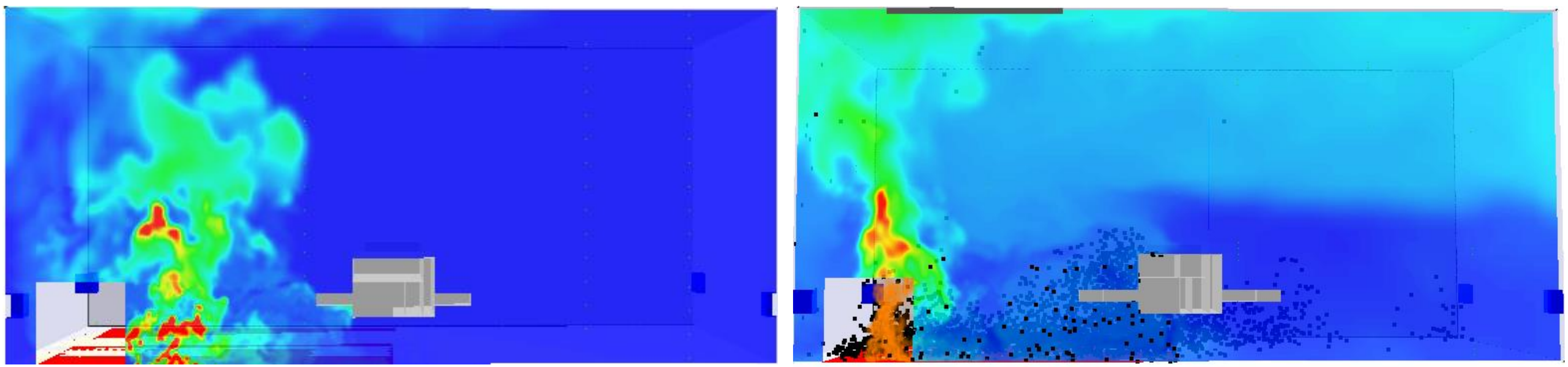
Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted

Y_{H_2O} at 40 and 120 seconds



t=40 sec

t=120 sec



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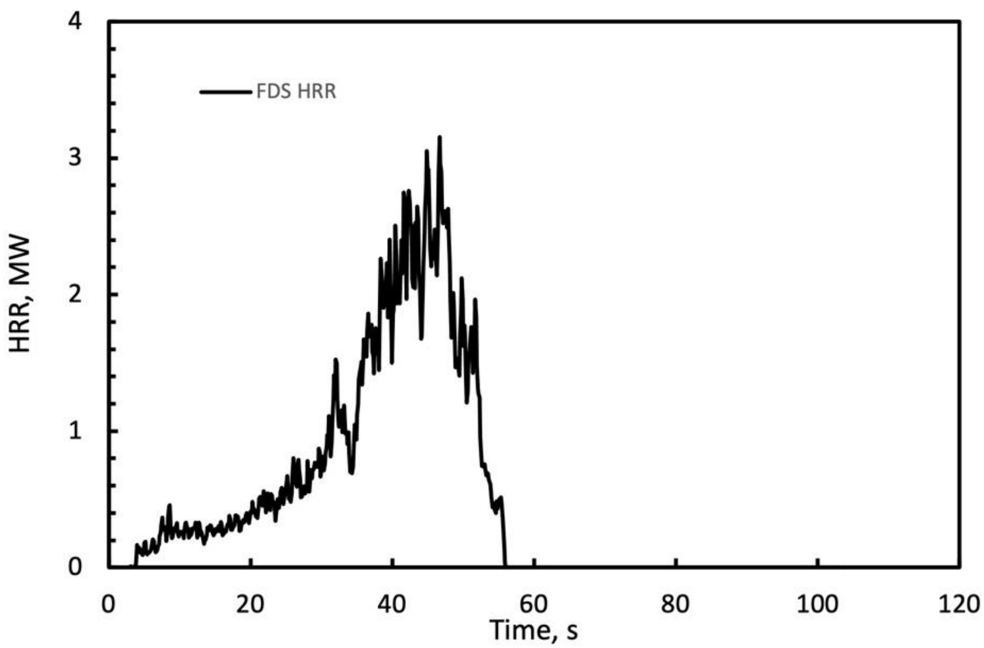
Simulation Results B.3 (Nozzle A&B)

Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted



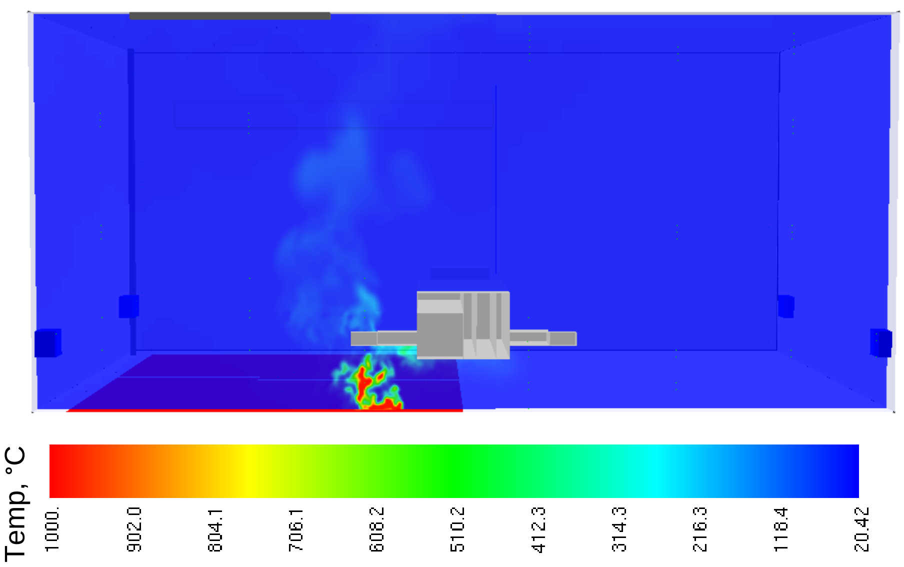
Performance Criteria

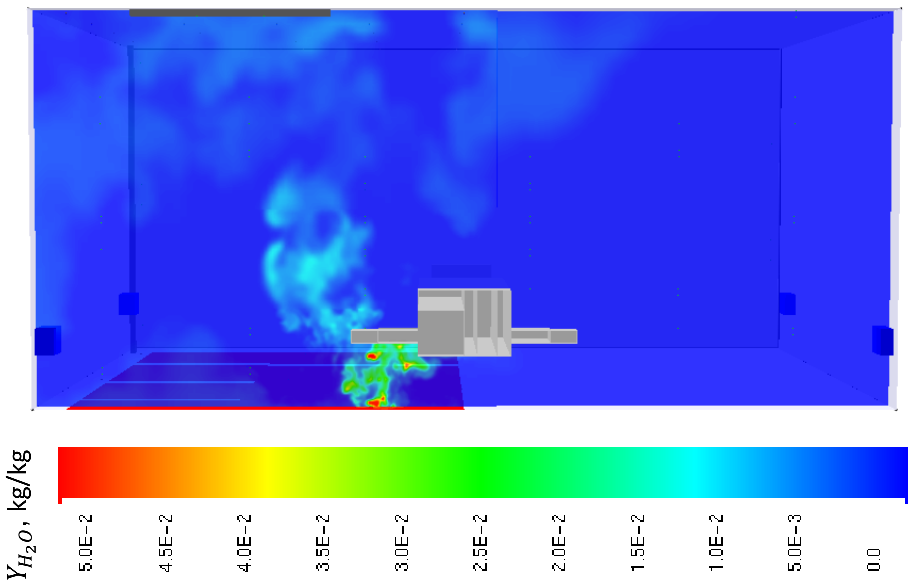
+ Peak HRR: < 3.2 MW *(w/o suppression 100 MW at 60 seconds)*
+ Max instantaneous structural steel temp: < 60 °C
+ Max incident heat flux to plane: < 85 kW/m^2
  - Ignition source side of fuel spill (under plane)

Simulation Results B.3 (Nozzle A&B)

Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted

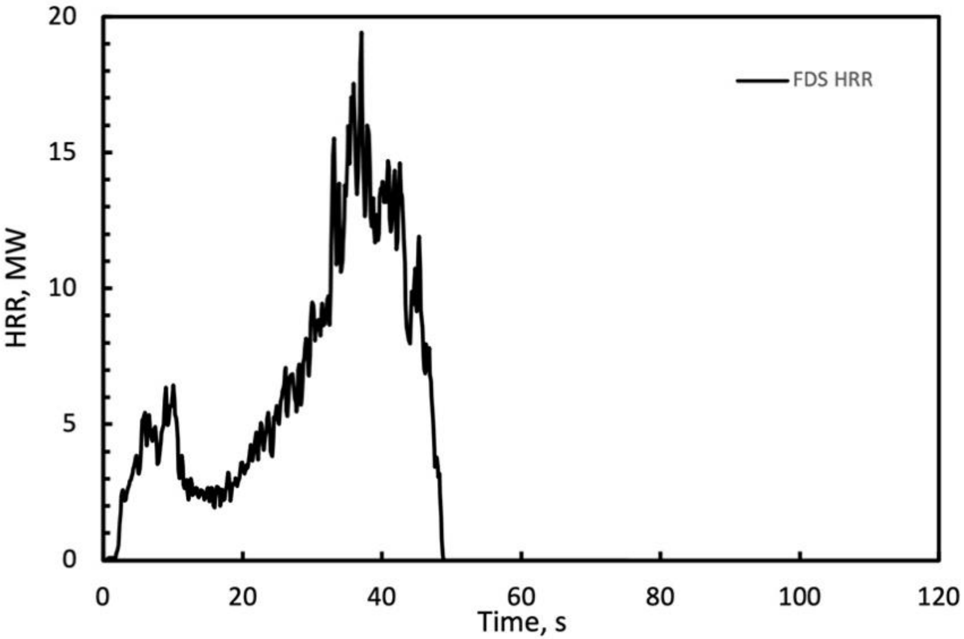
Temperature (left) and Y_{H_2O} (right) at 35 seconds





Simulation Results C.1 (Nozzle C)

Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted



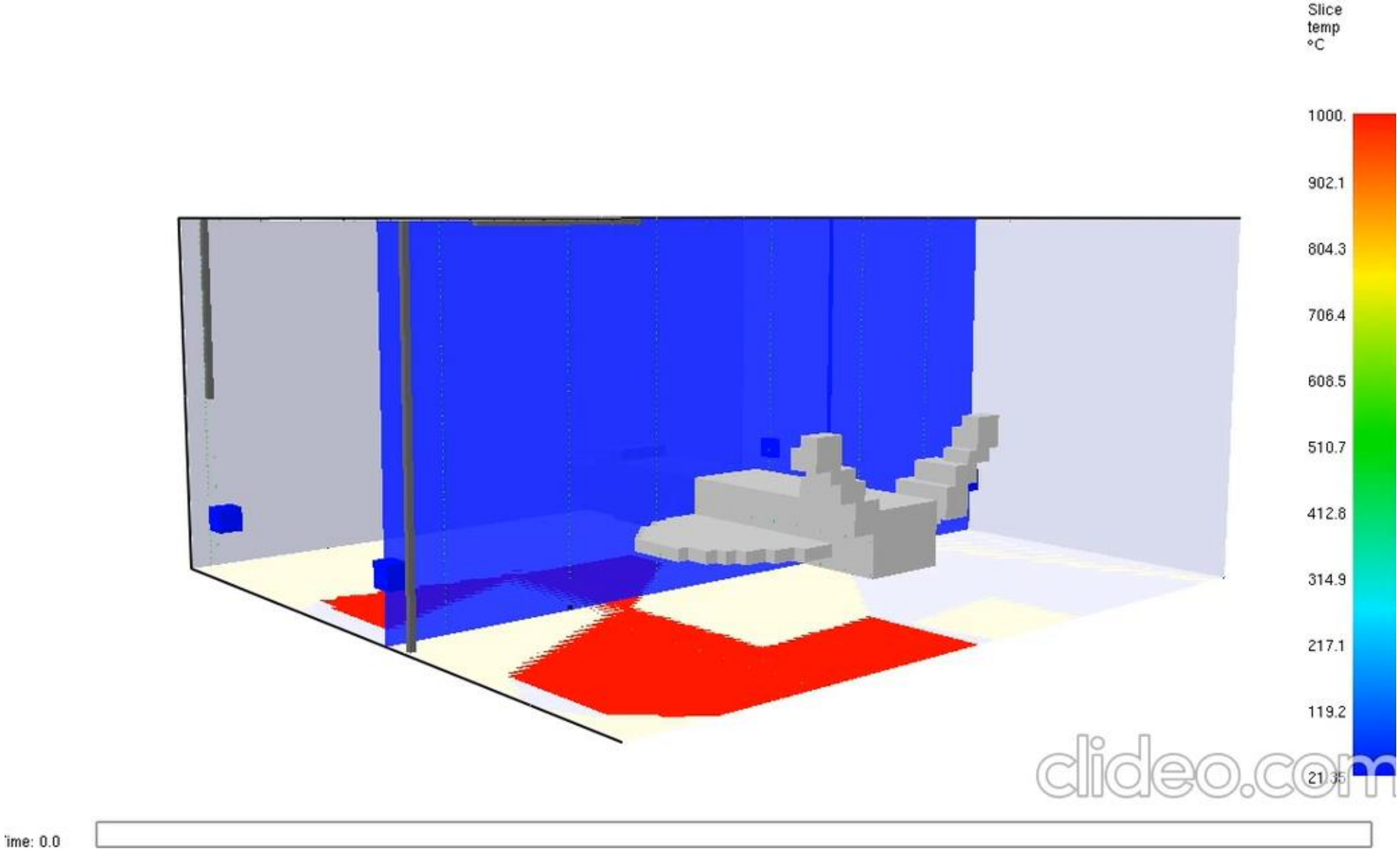
Performance Criteria

- Peak HRR: < 20 MW
  (w/out suppression 100 MW at 60 seconds)
- Max instantaneous structural steel temp: < 300 °C
- Max incident heat flux to plane: < 5 kW/m^2

Simulation Results C.1 (Nozzle C)

Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted

Video showing temperature, HRRPUV, and water particles



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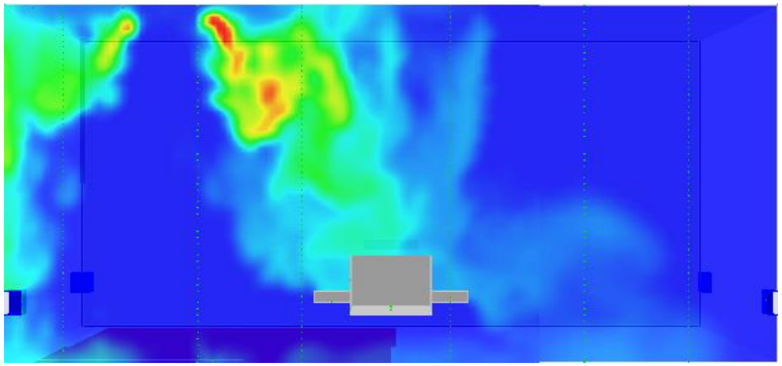
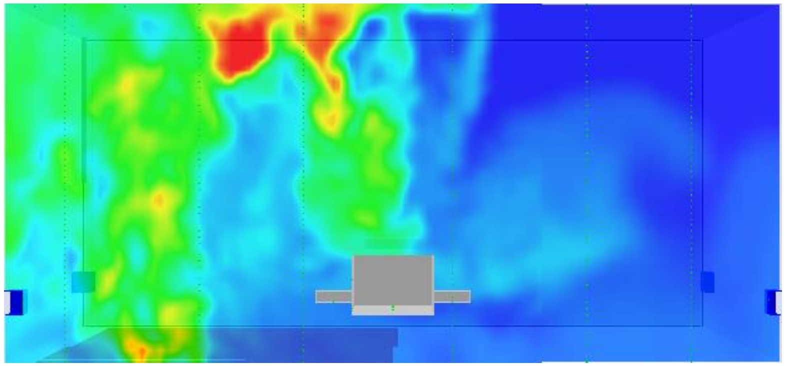
Nozzle A: Low pressure ceiling mounted
Nozzle B: Low pressure, floor pop-up
Nozzle C: High pressure, ceiling mounted

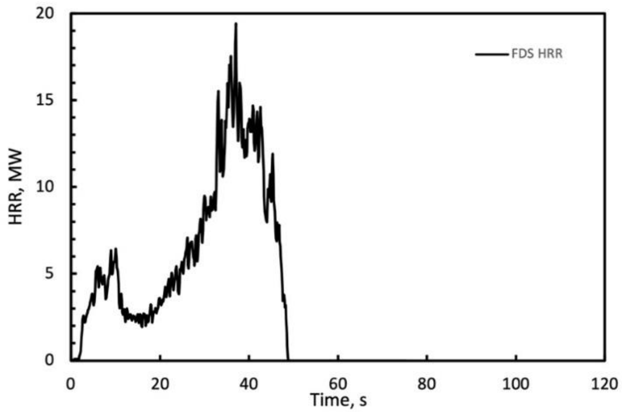
Y_{H_2O} at 35, 40, and 50 seconds

t=35 sec

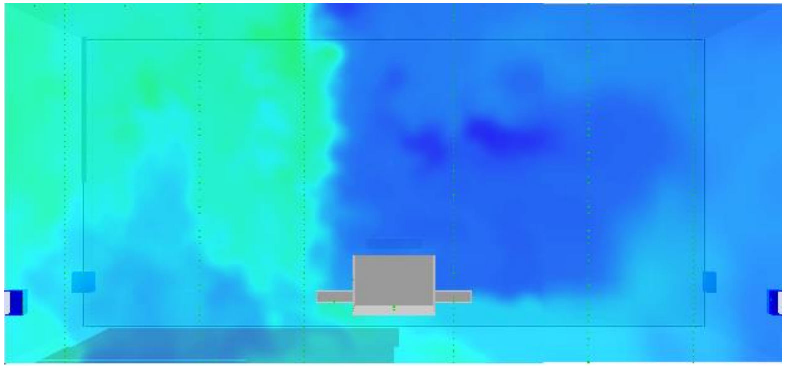


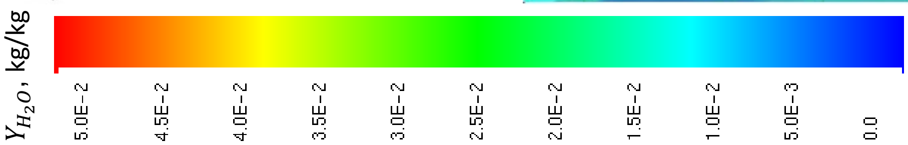
t=40 sec





t=50 sec





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Conclusions

- Seven manufacturers (10 combined water mist systems) were identified as potential candidates to provide successful protection from pool fires in aircraft hangars
- Water mist nozzles are highly grid dependent
- High pressure water mist nozzles must use the parameter PARTICLE_CFL =.TRUE
- Nozzle A alone is not able to suppress or extinguish a large JP-8 fuel spill
- Nozzle B is able to prevent the fire from growing at the expected rate, but the floor nozzles alone are not able to extinguish the fire
- Both Nozzle C and Nozzle A/B combined can extinguish this fire.
  - Simulation C.1 reaches a peak HRR of ~ 20 MW vs Simulation B.3 maintains a peak HRR less than 4 MW.
  - Floor nozzles generally cause the flame structure to deform more than the ceiling nozzles → higher heat fluxes to the aircraft

Questions?

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