Prediction of Fire Extinguishing Agent Concentration in Engine Core Compartment

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Jaesoo Lee

Boeing Commercial Airplanes
Seattle, Washington, USA

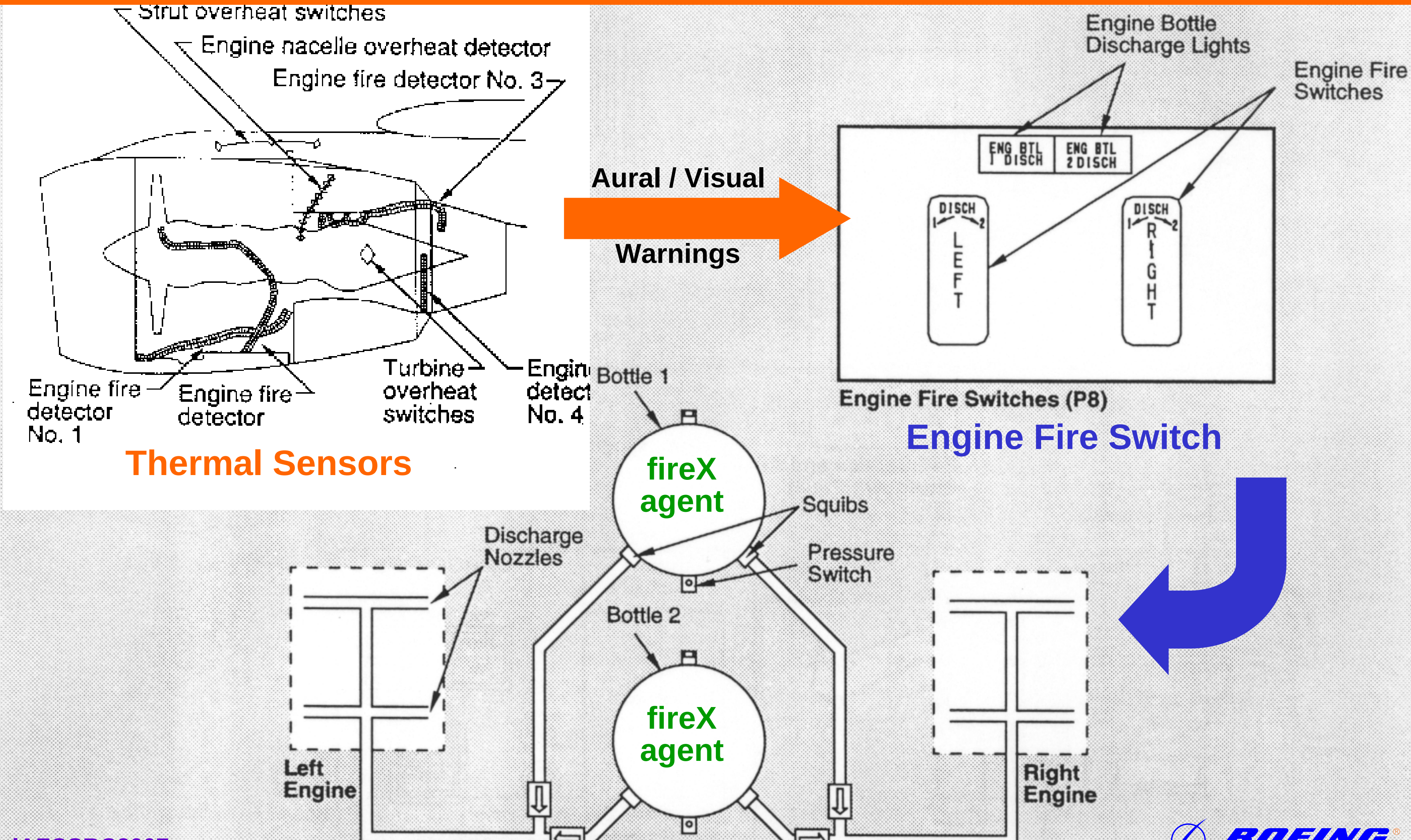
Outline

- Introduction
- Fire Extinguishing Process
- Simulation Methods
- Applications
- Results and Discussion
- Conclusions

Developed Simulation Tool

- **Based on Transport Model Eqs. of the Conservation of Mass, Momentum, and Energy of Air / Agent Flows.**
- **Analytical Tool to Guide Design / Installation of FireX Systems for Engines and APUs**
- **Performance Analysis of FireX System Designs using Halon and Replacement Agents at Flight Conditions of Interest.**
- **Saves Time and Cost by Complementing FAA Certification Tests.**

Engine Fire Extinguishing

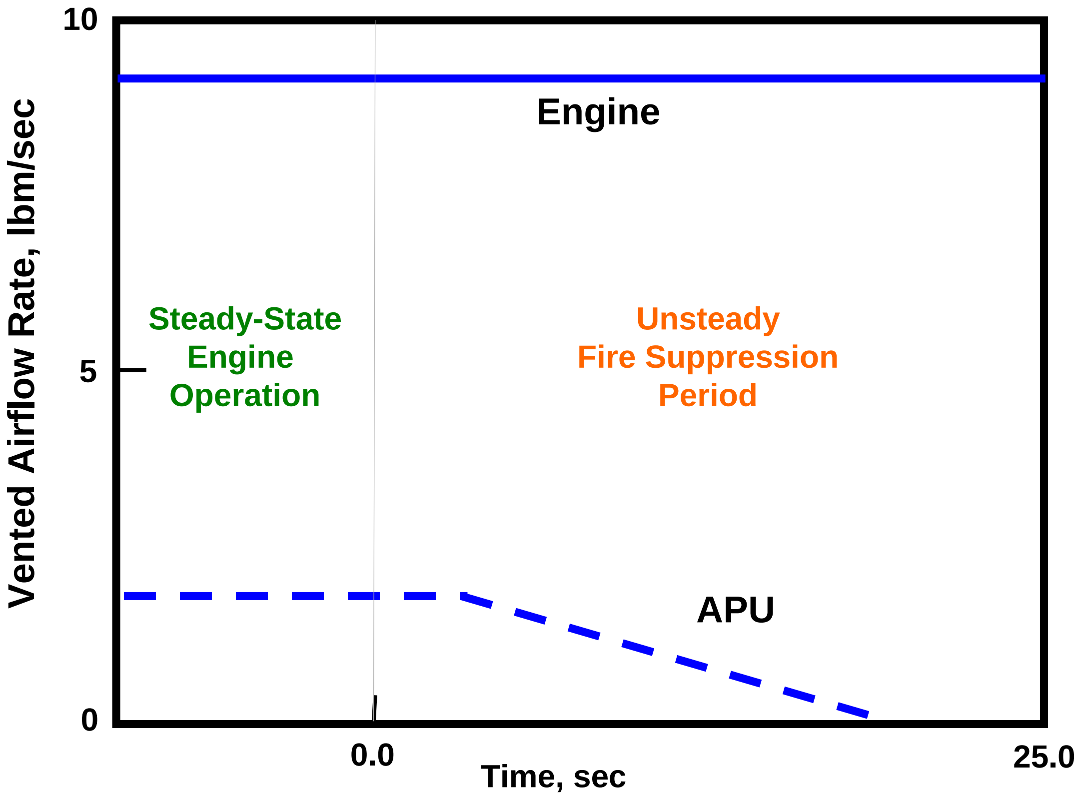


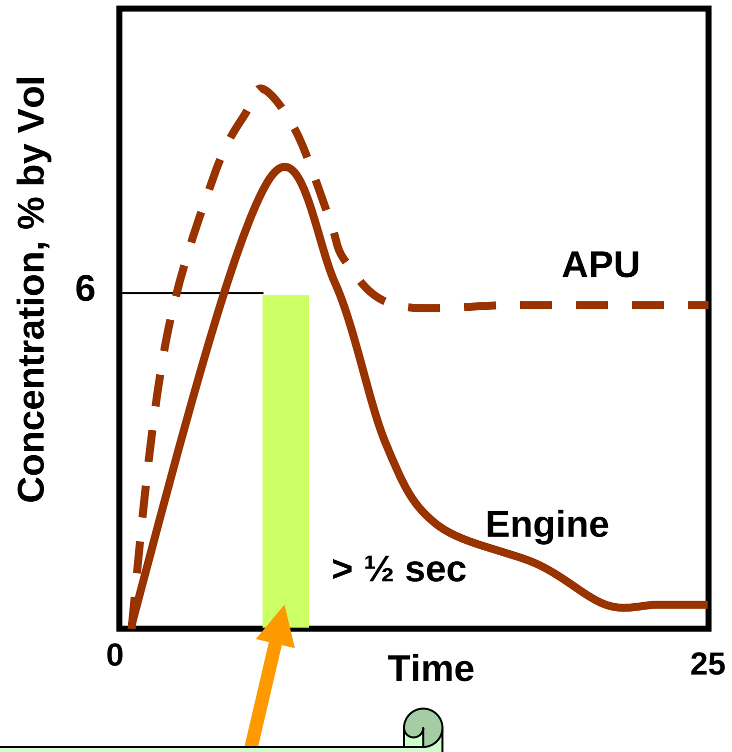
BOEING

Environmental and Physical Properties
(Halon 1301 and Alternate FireX Agents)

Thermodynamic Properties	Halon- 1301	HFC-125	CF_3I	HFC-227ea
Chemical Formula	$CBrF_3$	C_2HF_5	CF_3I	CF_3CHFCF_3
Molecular weight (kg/kg-mol)	149	120	196	170
Ozone Depletion Potential (ODP)	16	0	0.0002	0
Global Warming Potential (GWP)	5,600	2,800	5	2900
Atmospheric Lifetime (years)	65	33	5 Days	36.5
NOAEL[1], vol %	5.0	7.5	0.2	9.0
LOAEL[1], vol %	7.5	10.0	0.4	10.5
Boiling point (°C)	-57.8	-48.6	-22.5	-16.3
Critical Point (°C)	67.0	66.3	122	102
Critical pressure (Mpa)	3.95	3.62	3.882	2.91
Saturation pressure (Mpa)[2]	1.61	1.38	0.49	0.453
Critical density (kg/m^3)	745	571	872	621
Liquid density (kg/m^3)[2]	1551	1190	2,106	1386
Liquid Specific heat ratio, (kJ/kg K)[2]	0.881	1.358	0.43	1.177
Latent Heat of Vaporization, (kJ/kg)[3]	111	160	106	131

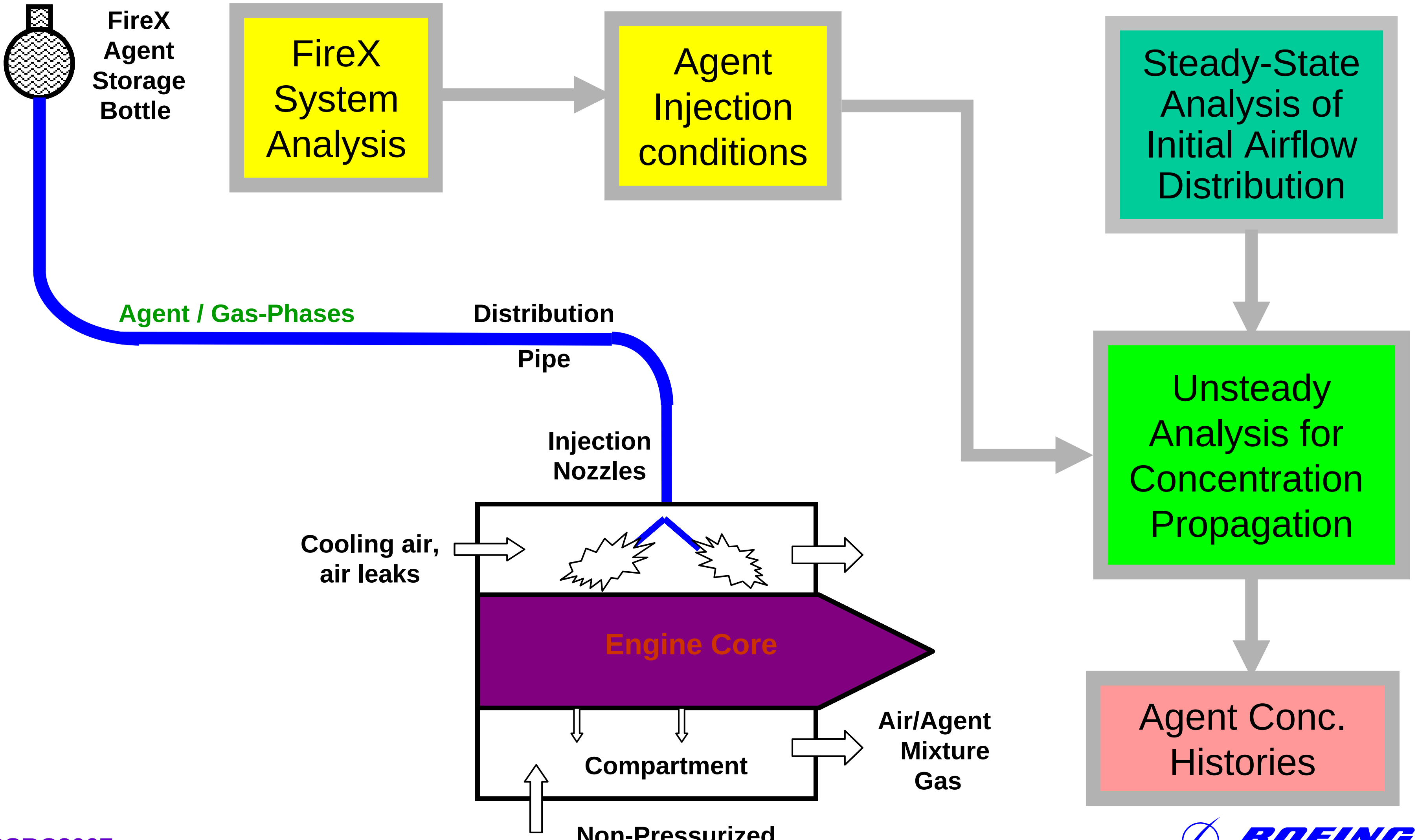
Vented Airflows and Concentration Histories During Fire Suppression Process





FAA AC 20-100: *If Halon 1301 is used as the fire extinguishing agent, the minimum agent concentration is 6 % by volume for a minimum of 0.5 seconds for all 12 concentration probe locations, simultaneously.*

Fire Extinguishing and Simulation Processes



Analysis of Agent Flow at Injection Nozzle

FireX Design Data

Agent mass, Bottle Vol., P (Charge), T (Charge), T (Test), D (Pipe), L (Pipe) d (Nozzles)

Input

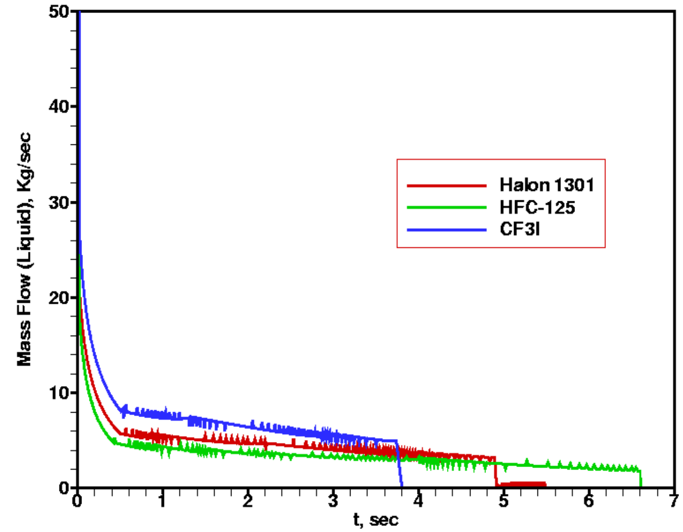
FireX System Analysis (Hflowx)

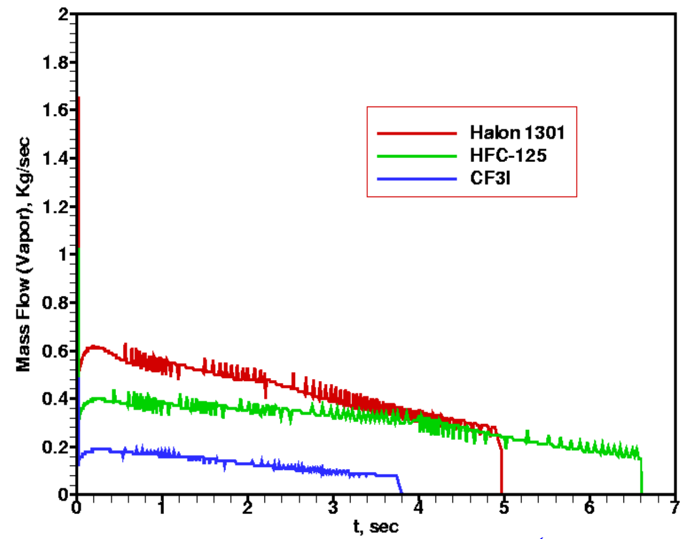
Output

Input

Agent Property Correlation Equations

Molecular weight, liquid density, vapor enthalpy, liquid enthalpy, latent heat of vaporization, vapor heat capacity, liquid heat capacity, Henry's law constant, liquid viscosity, vapor viscosity, surface tension, partial specific volume of N_2 in liquid agent





CFD Models for Agent Injection Conc. Propagation in a Vented Compartment

Discrete Agent Droplets

Lagrangian Model Eqs.

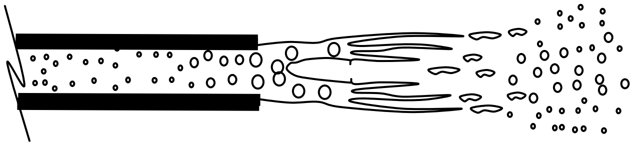
- Mass Transport Eq. (Evaporation)
- Momentum Transport Eqs. (Trajectories)
- Energy Transport Eq. (Heat Transfer)

2-way coupling

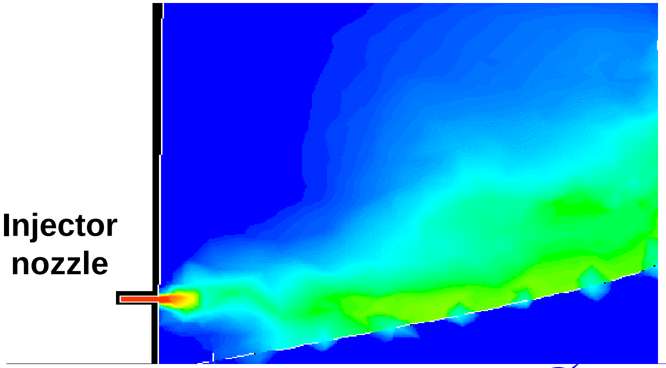
Air / Agent-Vapor Mixture

Eulerian Model Eqs.

- Mixture Mass Continuity Eq.
- Mixture Momentum Eqs.
- Mixture Energy Eq.
- Species Transport Eq.
- Mixture Turbulence Model Eqs.

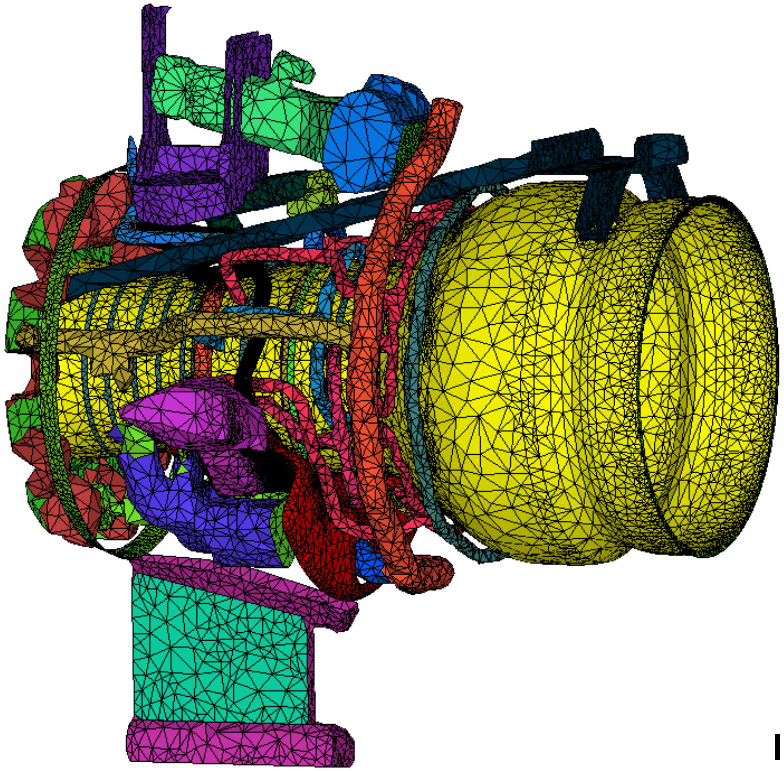


Liquid / Gas Mixture Jet
from Injector Nozzle

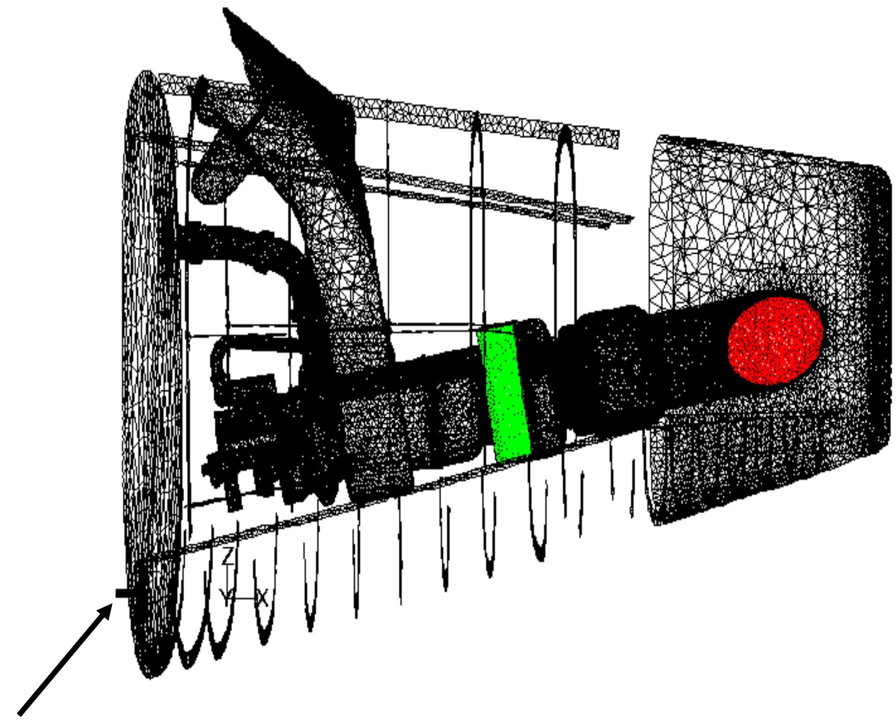


Compartment Geometry and CFD Meshes

Injection nozzles and external engine case are not shown.



Engine



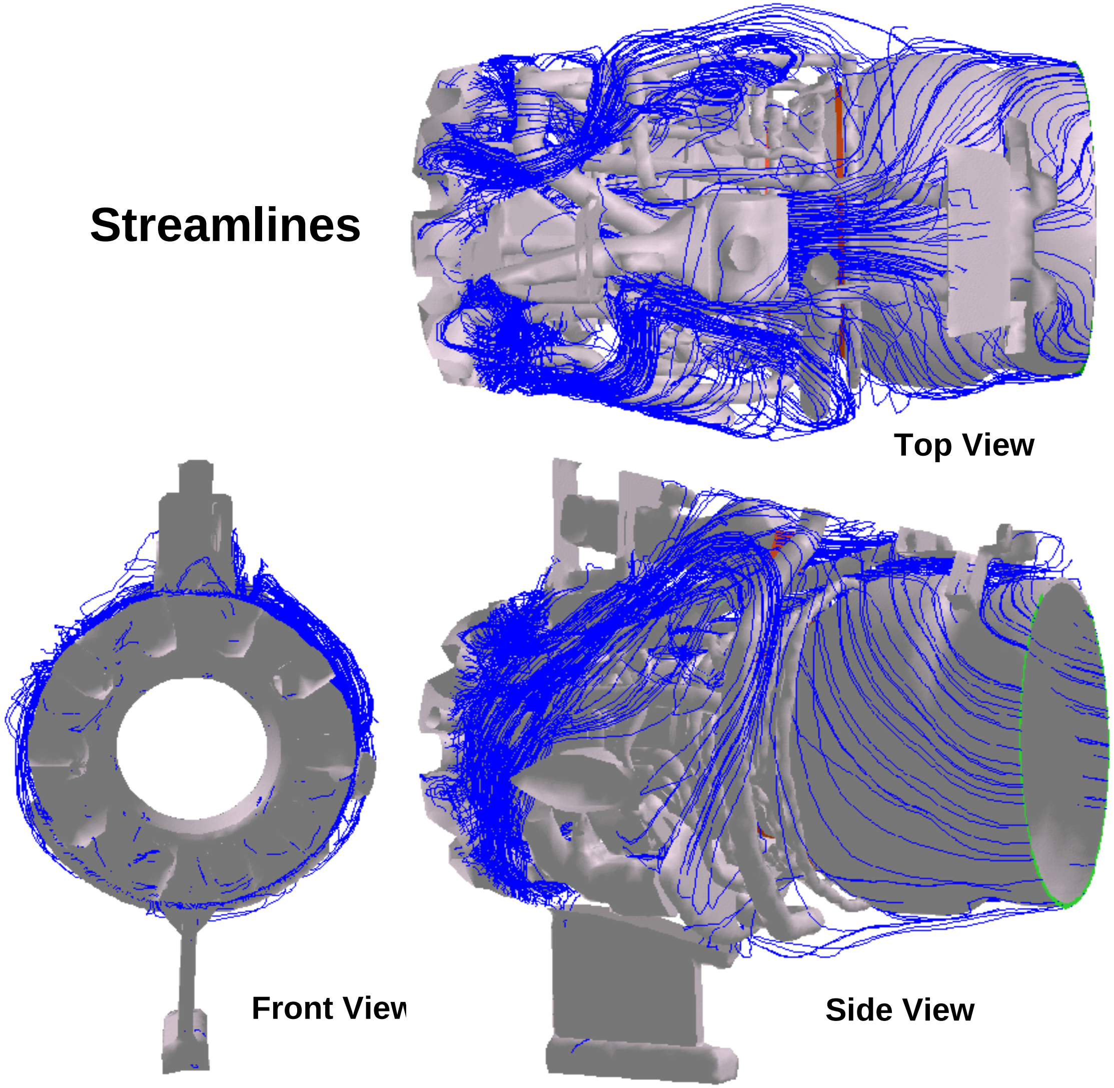
APU

Steady-State Analysis of Airflow inside Engine Core Compartment

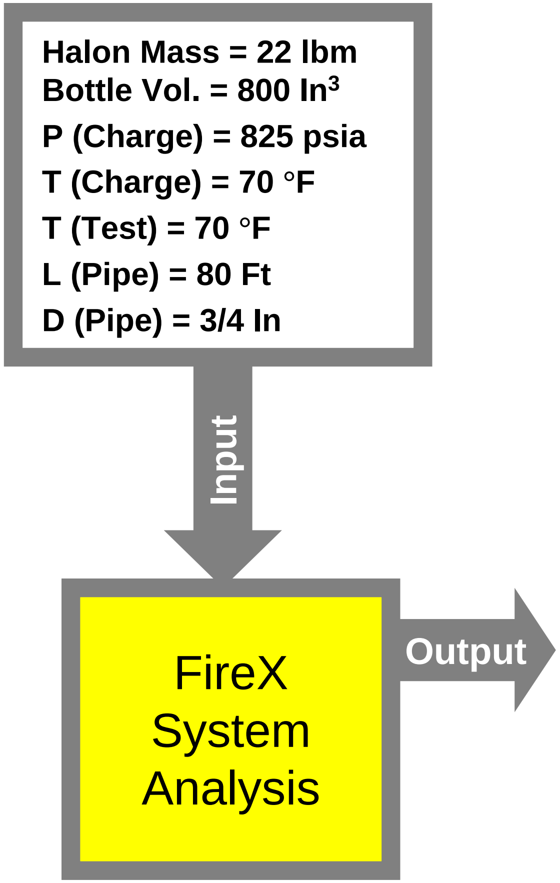
Inflow Boundary Conditions

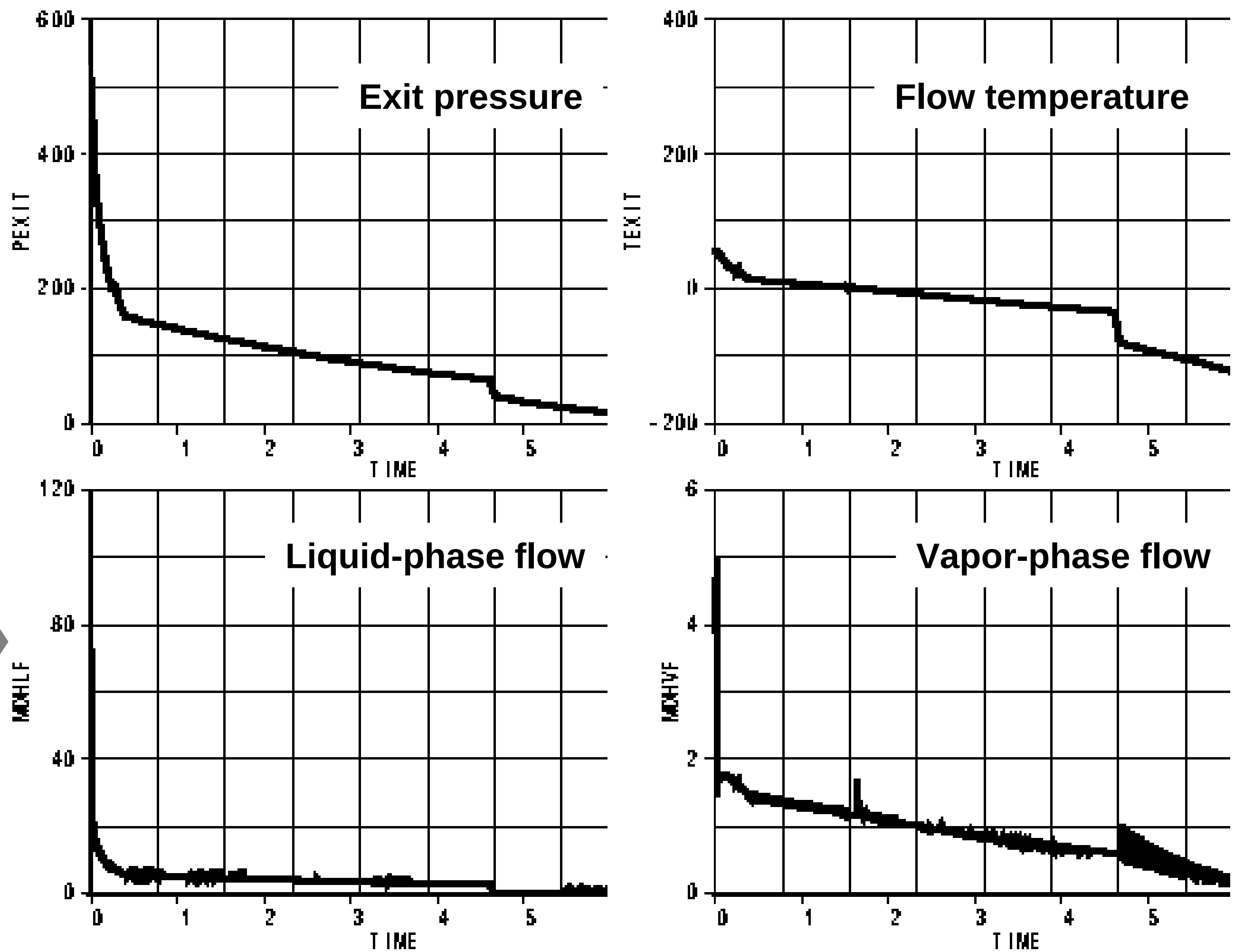
Airflow Sources
Pre-cooler
Equipment Cooling
HPT ACC
LPT ACC
Pipe Leakages
Core Leakages
Fan Leakages

Streamlines



Boundary Conditions for Injection Nozzles





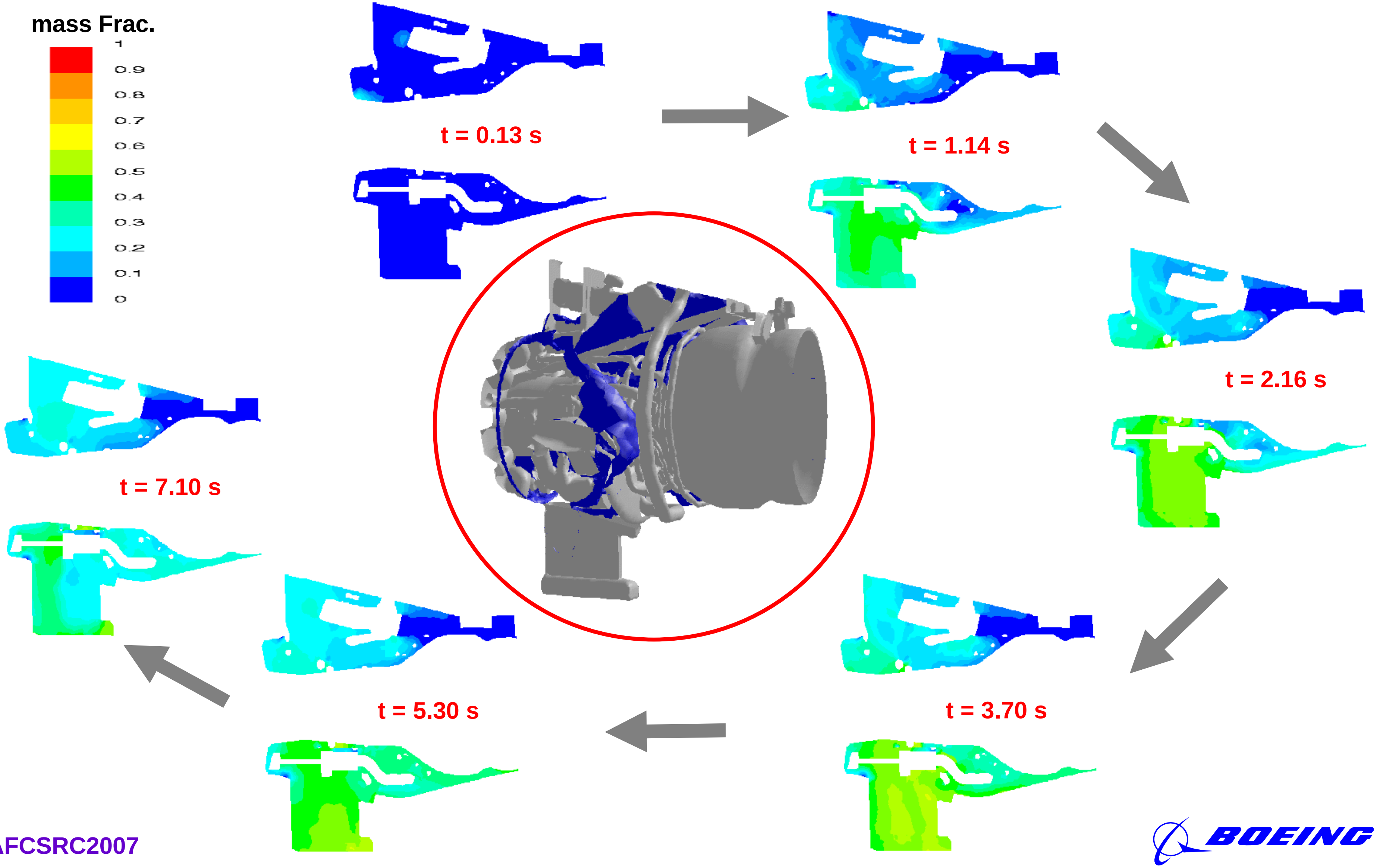
Unsteady Analysis of Air / Agent Flows (Flow Physics Models)

Simulation Models / BCs	Conditions
airflow boundary conditions	same as steady-state boundary conditions
agent injection BCs	Hflowx predictions
turbulence Model	Spalart-Allmaras 1-Eq. model
density of vapor agent	ideal gas law
liquid droplet break-up	KHRT model
agent injection type for Discrete Particle Model	surface injection

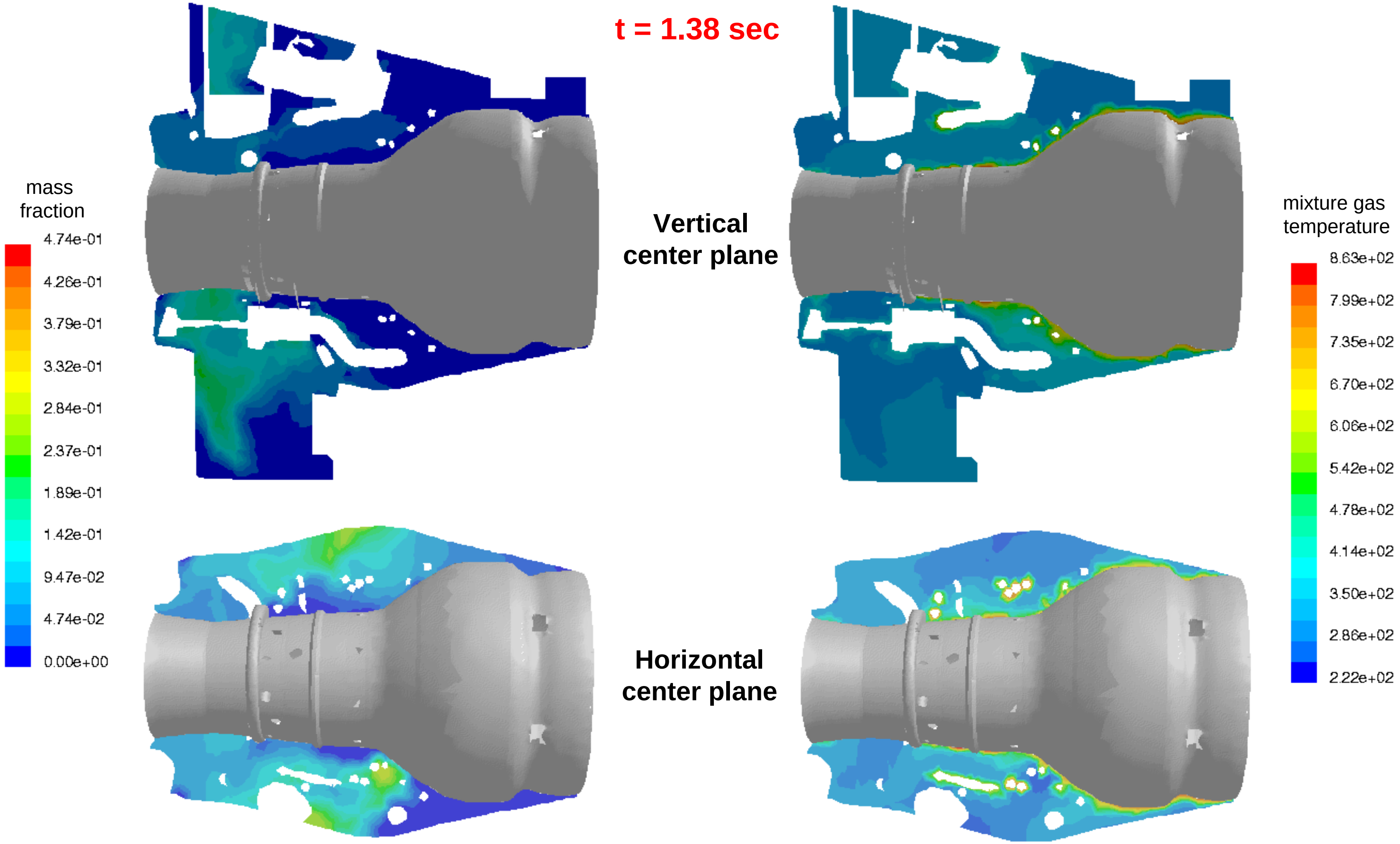
Unsteady Analysis of Air / Agent Flows (CFD Solution Scheme)

Solution Controls	Conditions
time-marching scheme	2nd–order implicit
marching time-step	0.1 ~ 10 msec
iterations per DPM calculation	20
discretization scheme	2nd –order upwind
calculation precision	double-precision
under-relaxation scheme	all transport equations
buoyancy / gravity effects	yes

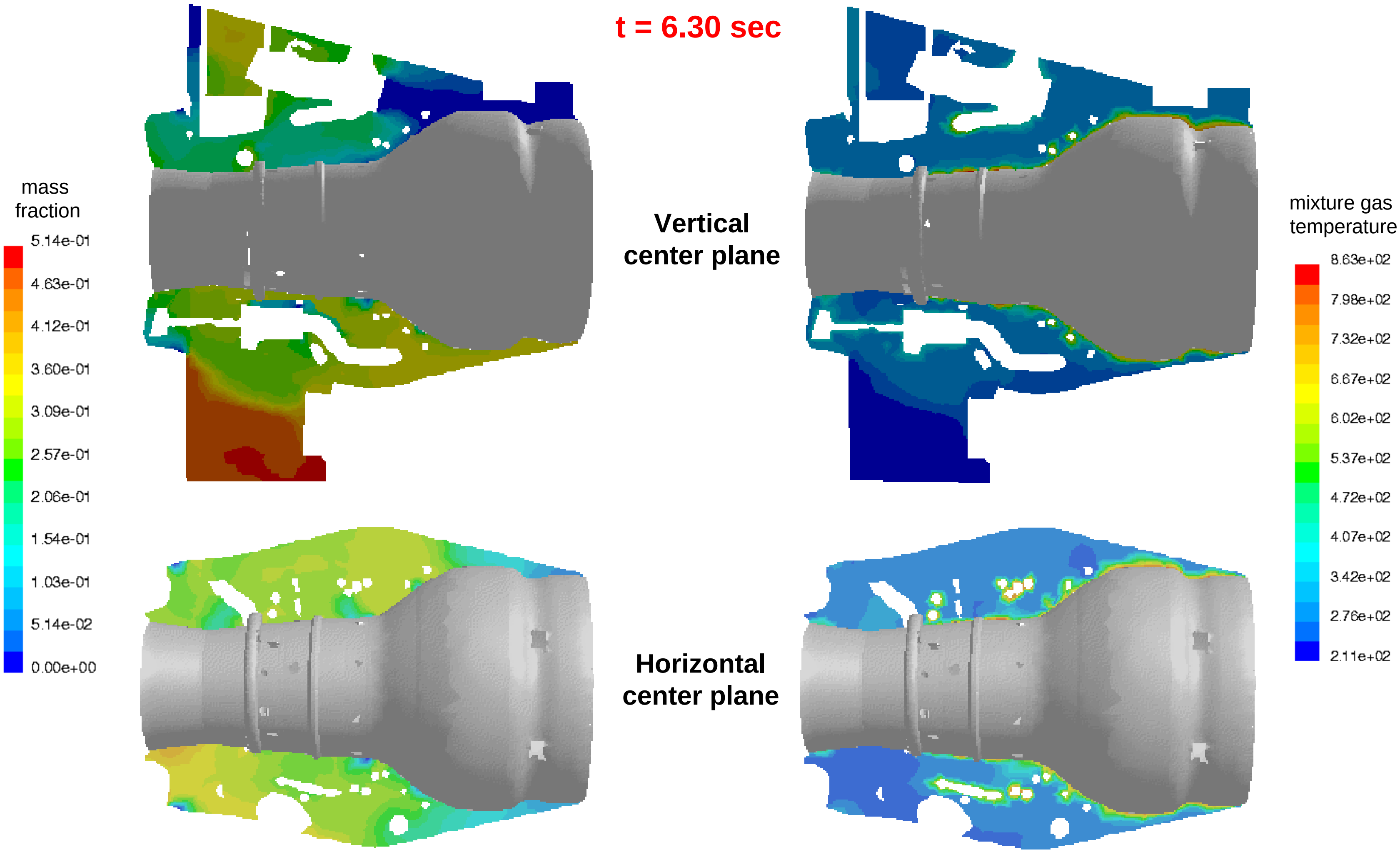
Predicted Unsteady Concentration Distribution



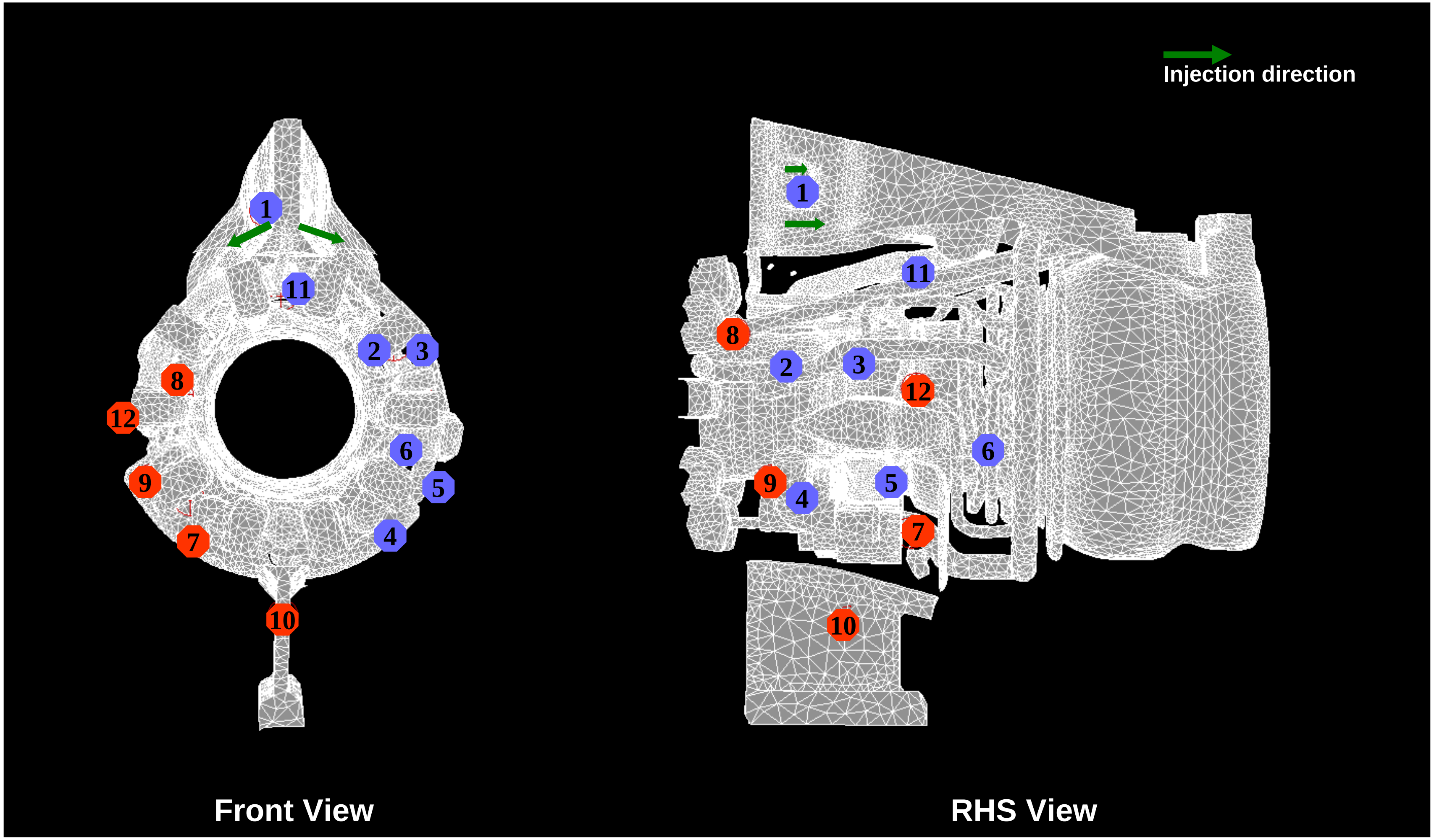
Agent Concentration / Mixture Temperature



Concentration / Mixture Temperature

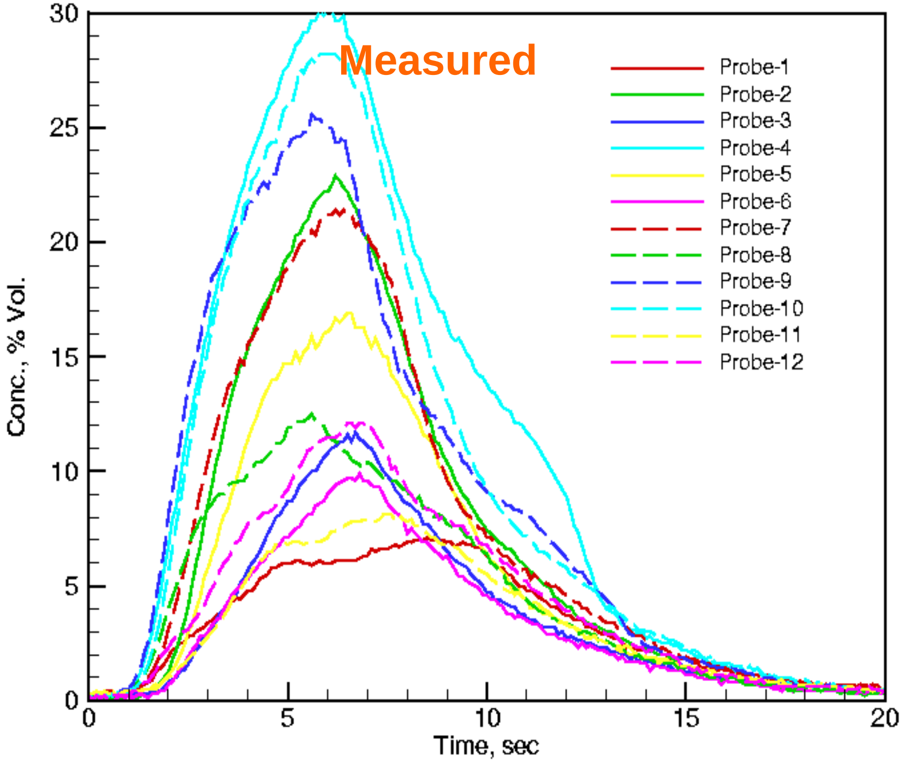


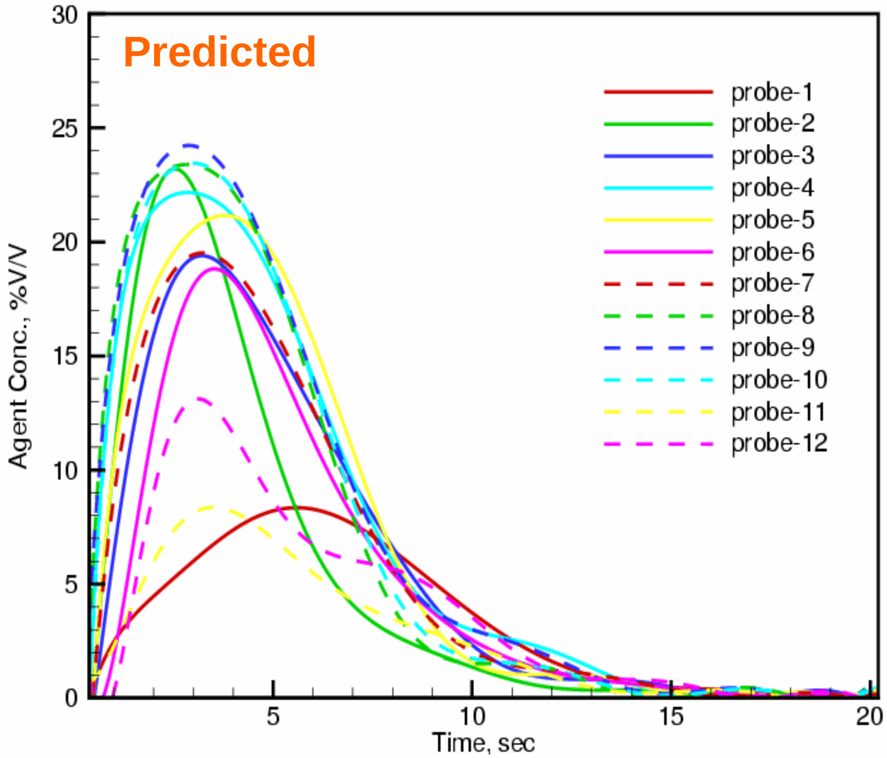
Injection Nozzles / 12 Probes Locations



Halon 1301 Concentration Histories – Case1

Bottle Temperature = 70 °F, Test Altitude = Ground





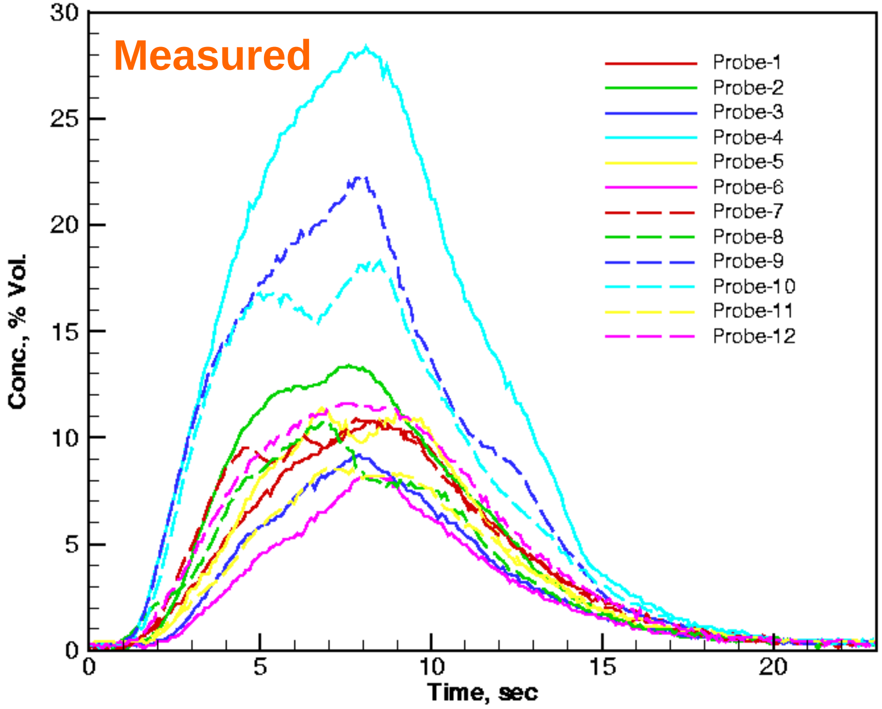
% Vol = 100 f_h / [f_h + (1 - f_h) ($\mathcal{M}_h/\mathcal{M}_a$)]

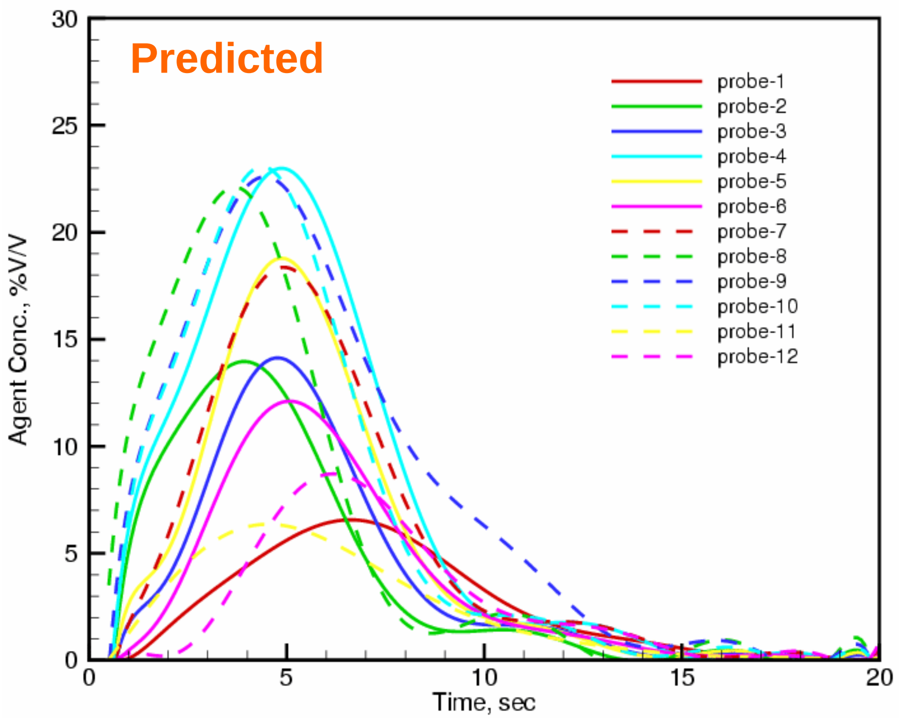
f_h = Mass fraction of agent vapor

$\mathcal{M}_h$, $\mathcal{M}_a$ = Mol. weights of agent vapor and air

Halon 1301 Concentration Histories – Case 2

Bottle Temperature = -65 °F, Test Altitude = Ground





Important Factors for Accurate Simulation

- Improved flow physics model for discharging and flashing agent jet flow from injection nozzle.
- Accurate boundary conditions for all airflow sources.
- Accurate geometry modeling inside engine core compartment.
- Refined discretization of CFD mesh and computational time step in simulating agent jet flows during injection period.
- Higher number density and poly-dispersed size groups in modeling discrete liquid agent droplets at injection nozzles.
- Accurate thermodynamic properties of agent over a broader range of T and P.

Conclusions

- A simulation method for predicting fire extinguishing agent concentration in engine core and APU compartments has been developed.
- Capabilities of the methods have been demonstrated by validation analyses of fireX tests of engines.
- Predicted concentration histories inside engine core compartment were well correlated with certification test data.
- Effective simulation factors for improved prediction accuracy are identified.