Development of a Multi-Sensor Cargo Compartment Fire Detection Alarm Algorithm

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Federal Aviation Regulation 25.858

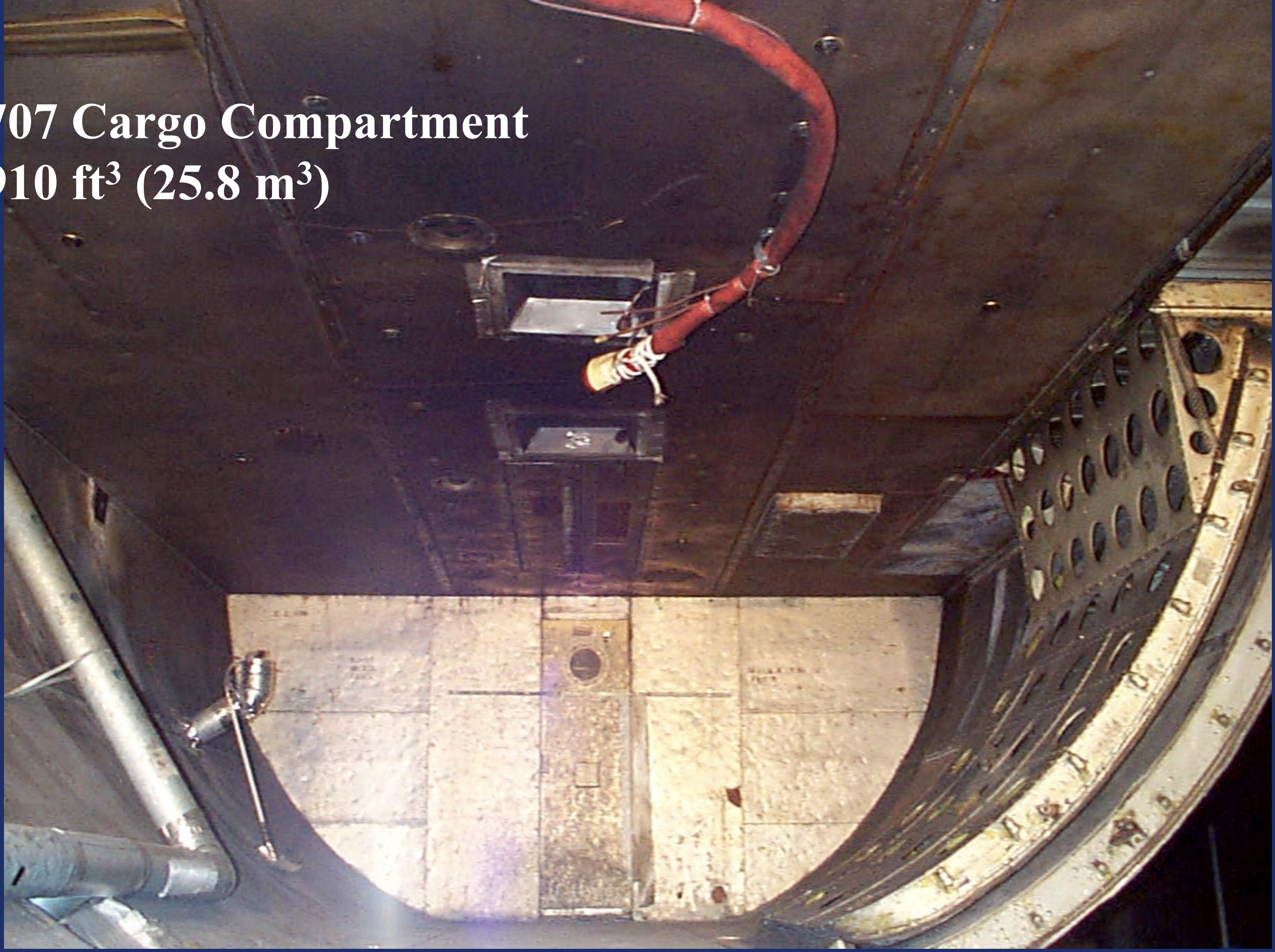
Requires that the cargo compartment fire detection system provide a visual indication to the flight crew within one minute of the start of a fire.

Problem

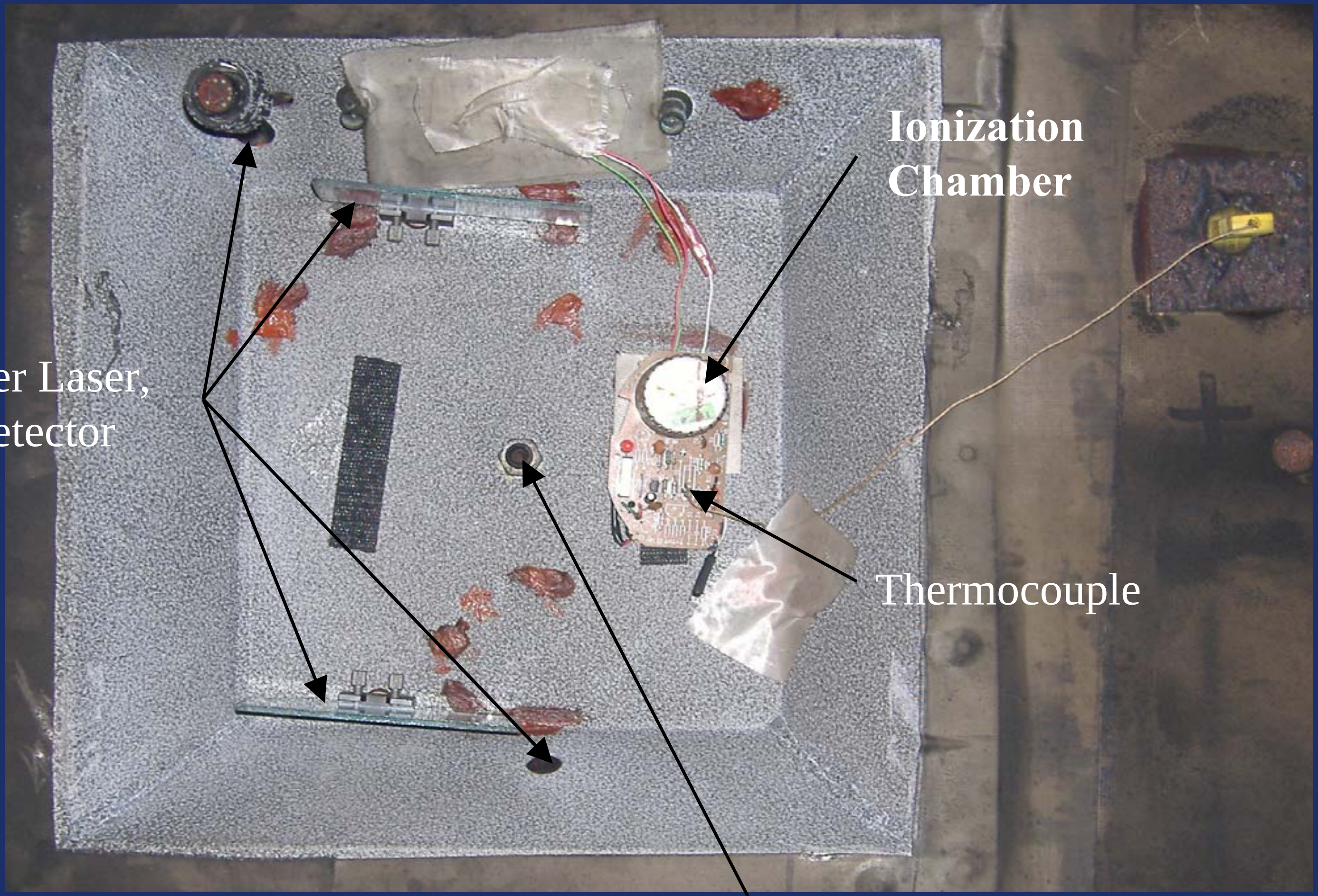
- The majority of currently installed fire detectors are photoelectric smoke detectors that can not differentiate between smoke particles and other airborne particles such as dust and condensation.

- The ratio of false alarms to the detection of actual fires in the cargo compartments of U.S. registered aircraft is on the order of hundreds to one.

707 Cargo Compartment
910 ft^3 (25.8 m^3)



Recessed pan in 707 ceiling



Fire Sources

Resin Block

Shredded Newspaper

Pan of Alcohol

Alcohol Soaked Rags

Urethane Foam

Suitcase with Rags

Nuisance Sources

Vaporizer

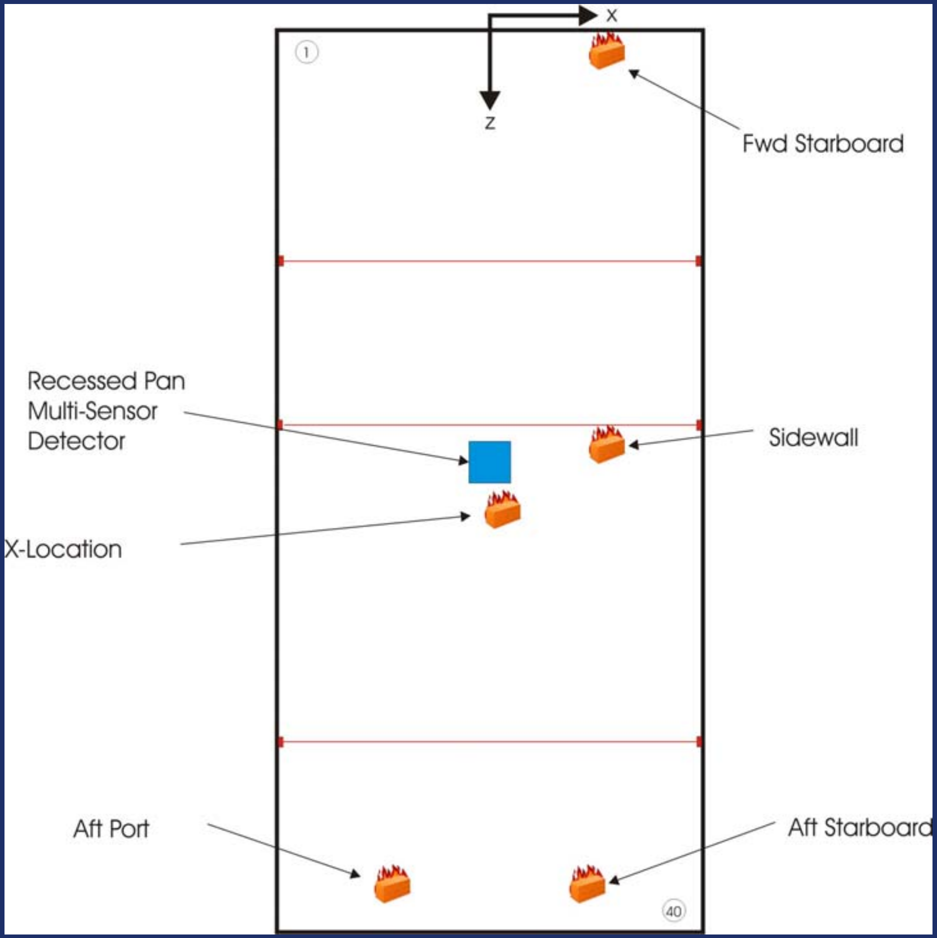
Heat Gun

Engine Exhaust

Dust

Human Respiration (CO_2)

Tests were conducted at numerous locations throughout the cargo compartment to generate a matrix of sensor readings for various fire and nuisance types and locations.



	MIC (Volts)	Rate-Rise (Volts/sec)	Smokemeter (%LT/ft)	Rate-Rise (%LT/ft/sec)	CO (ppm)	Rate of Rise CO	CO_2 (ppm)	Rate of Rise CO_2	Temp. Change (°F)	Temp. Rate of Rise
REFERENCE SOURCE										
Resin Block (X Location)	0.589	-0.522	48.743	-3.036	108.889	4.580	1497.116	49.026	9.831	0.815
PERIMETER TESTING										
Resin Block (Fwd)	0.583	-0.246	59.959	-1.522	86.243	3.571	1076.050	34.180	3.831	0.312
Resin Block (Aft)	0.447	-0.340	55.755	-0.010	88.763	2.369	997.473	58.431	6.782	0.302
Resin Block (Sidewall)	0.691	-0.391	53.372	-2.722	94.696	2.777	1245.117	24.185	5.352	0.332
NUISANCE SOURCE (X Location)										
Arizona Test Dust (Container)	2.801	-0.694	91.276	-1.798	0.088	0.047	0.135	0.078	0.037	0.018
Vaporizer (Fog formation)	4.822	-0.029	41.823	-4.653	0.107	0.076	5.231	0.619	2.159	0.289
Exhaust fumes (Forklift loading)	4.845	-0.046	94.126	-0.149	493.172	45.242	712.394	55.237	0.294	0.137
Heat Gun (Heated container)	1.854	-0.262	49.049	-3.982	0.274	0.106	0.539	0.144	22.967	0.889
Occupied compartment (Human)	4.850	-0.023	98.966	-0.029	0.095	0.024	307.159	23.041	0.087	0.026
PERIMETER TESTING										
Arizona Test Dust (Under pan)	2.705	-0.713	70.513	-10.582	0.045	0.028	0.103	0.087	0.046	0.031
Arizona Test Dust (2 feet)	3.110	-0.665	60.638	-19.684	0.045	0.028	0.103	0.087	0.046	0.031
Arizona Test Dust (4 feet)	4.990	-0.038	97.366	-1.308	0.045	0.028	0.103	0.087	0.046	0.031
FIRE SOURCES (X Location)										
FLAMING SOURCES										
Denatured Alcohol (40 mL)	4.552	-0.038	86.089	-1.239	1.624	0.119	1831.611	99.377	13.154	0.529

Alcohol-Soaked Rags	1.430	-0.322	83.655	-1.184	14.191	1.428	1880.348	110.544	14.674	1.016
Polyurethane Foam	1.390	-0.736	91.385	-0.702	15.128	2.211	2098.261	321.620	23.051	2.844
SMOLDERING SOURCES										
Shredded Newspaper	1.491	-0.497	51.799	-2.808	171.324	24.803	1994.328	276.974	33.145	2.398
Suitcase	1.965	-0.103	64.367	-1.744	372.643	10.697	346.922	9.406	1.423	0.095
PERIMETER TESTING										
Alcohol-Soaked Rags (Average)	1.341	-0.257	95.627	-0.195	21.074	1.508	1885.504	83.748	4.619	0.117
Polyurethane Foam (Average)	1.216	-0.247	94.604	-0.373	6.703	0.779	2070.223	192.934	5.699	0.200
Shredded Newspaper (Average)	0.785	-0.695	72.410	-2.449	157.376	19.125	1912.648	214.622	13.945	0.391
Alcohol-Soaked Rags (Fwd)	1.370	-0.271	96.955	-0.279	2426.18	112.548	1678.543	50.625	3.659	0.166
Polyurethane Foam (Fwd)	1.278	-0.501	92.476	-0.754	1011.26	157.490	2044.346	385.902	5.910	0.276
Shredded Newspaper (Fwd)	0.497	-0.990	74.829	-1.475	1194.61	140.035	1764.622	369.124	12.777	0.670
Alcohol-Soaked Rags (Aft)	1.198	-0.287	90.787	-0.512	1385.88	172.563	2032.288	46.734	5.055	0.139
Polyurethane Foam (Aft)	1.074	-0.431	94.169	-0.375	838.361	43.948	2096.167	124.795	6.656	0.225
Shredded Newspaper (Aft)	0.942	-0.745	69.521	-3.422	1952.91	367.176	2060.719	429.367	15.327	0.651

Five Alarm Algorithms were Designed

1. IF {(CO ppm >2 OR CO_2 ppm >30) AND (°F >3 OR MIC volts <4.7) AND (%LT/ft <97)} THEN →ALARM

Absolute values of gases AND Temperature OR MIC OR Smoke absolute values

2. IF {(d[CO]/dt >1 OR d[CO_2]/dt >10) AND (d[%LT/ft]/dt >0.1 OR d[MIC]/dt >0.1 OR d[°F]/dt >0.15)} THEN → ALARM

Rate of change of gases AND rate of change of Smoke OR MIC OR Temperature

3. IF {(d[CO]/dt >1 OR d[CO_2]/dt >10) AND (d[%LT/ft]/dt >0.1 OR d[MIC]/dt >0.1 OR MIC volts <4.7)} THEN → ALARM

Rate of change of gases AND rate of change of Smoke OR MIC OR MIC absolute

Five Alarm Algorithms were Designed

4. IF {(CO ppm >2 OR d[CO]/dt >1) AND (MIC volts <4.7 OR

d[MIC]/dt >0.1 OR °F >3 OR %LT/ft <94 OR d[%LT/ft]/dt >0.15)} THEN → ALARM

CO AND MIC OR Smoke absolute OR rate of change OR temperature rise.

5. IF {(CO2 ppm >7.5 or d[CO2]/dt >5) AND (MIC volts <4.7 OR

d[MIC]/dt >0.1 OR °F >3 OR %LT/ft <94 OR d[%LT/ft]/dt >0.15)} THEN → ALARM

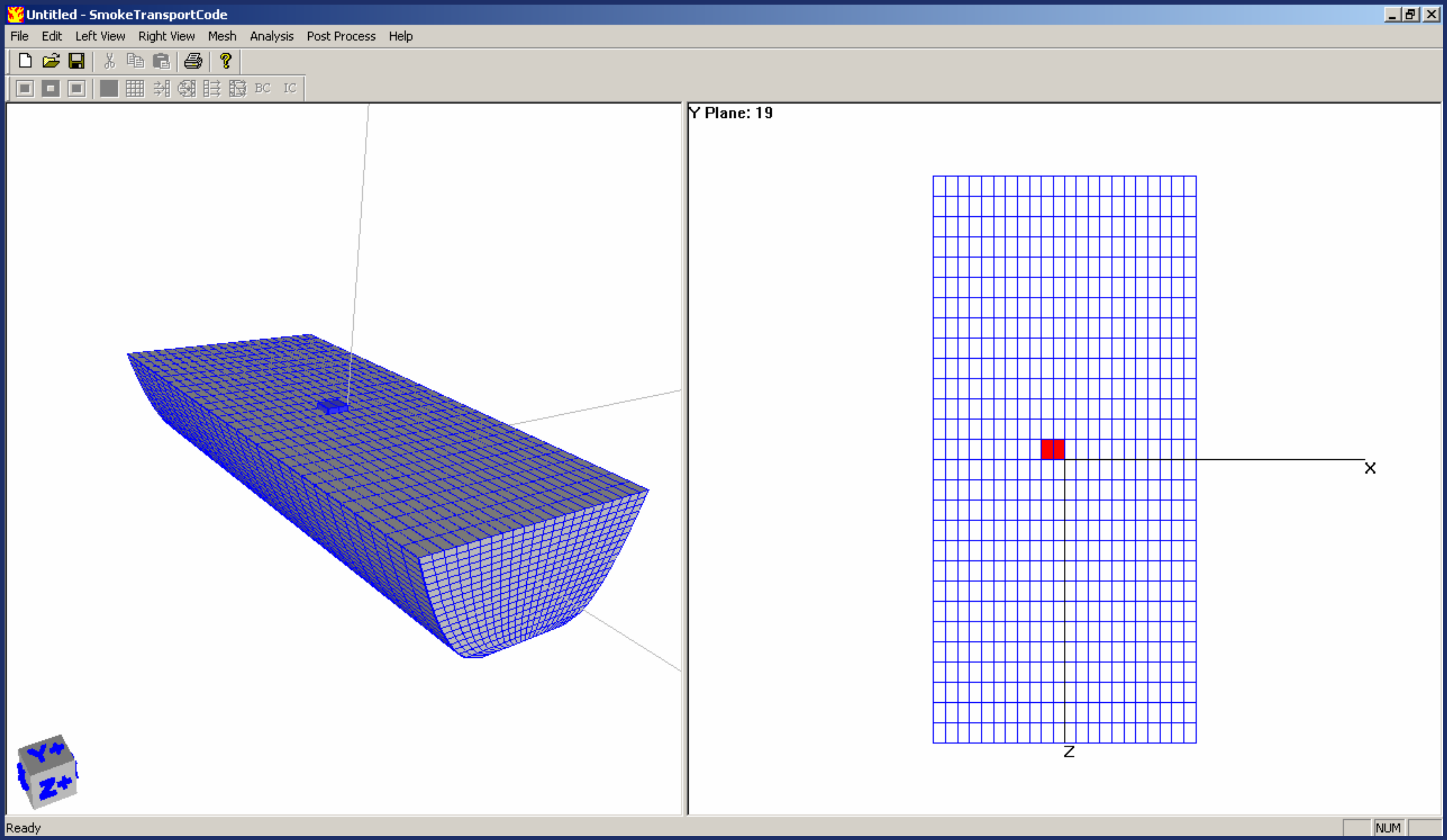
CO_2 AND MIC OR Smoke absolute OR rate of change OR temperature rise

	Algorithm						
	1	2	3	4	5	Photoelectric	Ionization
Total Tests	30	30	30	30	30	30	30
Failure	4	0	1	1	0	10	8
Successful	26	30	29	29	30	20	22
Successful %	87%	100%	97%	97%	100%	67%	73%

Successful is defined as returning an alarm in less than 60 seconds after the start of a fire and not returning an alarm for any nuisance source.

Fire Sources	Algorithm					Photoelectric	Ionization
	1	2	3	4	5		
(X Location)							
FLAMING SOURCES							
Denatured Alcohol (40 mL)	114	20	80	X	14	118	X
Alcohol soaked rags	22	14	14	18	14	32	14
Polyurethane foam	12	12	12	14	10	38	10
SMOLDERING SOURCES							
Shredded newspaper	20	16	16	18	16	20	18
Suitcase	60	44	44	46	44	62	126
PERIMETER TESTING							
Alcohol soaked rags (Fwd)	202	30	30	34	30	X	34
Polyurethane foam (Fwd)	24	24	24	28	22	22	20
Shredded newspaper (Fwd)	38	38	38	40	38	34	36
Alcohol soaked rags (Aft)	48	36	34	36	32	50	46
Polyurethane foam (Aft)	46	40	40	46	34	52	36
Shredded newspaper (Aft)	46	28	28	30	28	48	22

Sandia Cargo Compartment Smoke, Gas and Heat Transport CFD Code



Comparison of Experimental and Computational Alarm Times

Fire Sources	Algorithm					Photoelectric	Ionization
	1	2	3	4	5		
EXPERIMENTAL							
Resin Block (X-Location)	20	18	18	24	14	20	20
PERIMETER TESTING							
Resin Block (Fwd)	70	48	48	50	48	54	84
Resin Block (Aft)	50	50	50	54	50	50	42
Resin Block (Sidewall)	38	26	26	38	26	36	42
COMPUTATIONAL							
Resin Block (X-Location)	20	18	18	20	18	18	18
PERIMETER TESTING							
Resin Block (Fwd)	70	52	52	52	50	52	82
Resin Block (Aft)	50	50	50	50	46	48	48
Resin Block (Sidewall)	28	26	26	28	26	30	34

Difference in Alarm Times with Experimental Data Versus Computational Data (Seconds)

Fire Locations	Algorithm						
	1	2	3	4	5	Photoelectric	Ionization
Resin Block (X-Location)	0	0	0	4	4	2	2
Resin Block (Fwd)	0	4	4	2	2	2	2
Resin Block (Aft)	0	0	0	4	4	2	6
Resin Block (Sidewall)	10	0	0	10	0	6	8

Conclusions

•Multi-sensor alarm algorithms can simultaneously reduce false alarms to nuisance sources and increase sensitivity to actual fire sources.

•The Sandia smoke transport code is an effective tool to create a virtual smoke detector to test alarm algorithms and proximity to fire response times.