THESIS APPROVAL

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Master of Engineering (Safety Engineering)

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FIELD	**PROGRAM**

TITLE: Design of Early Warning Fire Detection (EWFD) Protection in Aircraft Cargo Compartments

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THESIS

DESIGN OF EARLY WARNING FIRE DETECTION (EWFD) PROTECTION IN AIRCRAFT CARGO COMPARTMENTS

SUDHA TONGGAMNERD

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the Requirements for the Degree of
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False alarms are a much more frequent event. A recent study places the false alarm to smoke detection ratio at 200:1 over the last five years in Commercial Transport Aircraft Cargo Compartments. A significant fraction of false alarms is thought to be due to nuisance sources such as condensed water vapor, and other aerosol sources.

There is no single physical parameter that would allow the detection of this wide fire spectrum with an evenly distributed sensitivity under these conditions, in the currently used systems, the smoke detectors have to be adjusted so as to early detect the fire type for which their sensitivity is basically the worst (and to meet the certification requirements); making them also more sensitive to environmental conditions.

Basically, a combination of several criteria to trigger a fire alarm would bring a significant benefit in terms of discrimination capabilities, provided of course that the fire and non-fire situations are well known. Therefore in order to improve significantly the fire detection reliability, it is necessary to better understand, under this environment, the physical parameters that distinguish the start of a fire from those that are due to non-dangerous phenomenon.

To review the fire detection system and Modification can only be improved on the basis of clear performance objectives, fire sources in this sense that their characteristics fire and non-fire scenario will be presented against which the performance of new fire detection concept can be measured and evaluated as well as environmental conditions and fire threats.

Student's signature　　　Thesis Advisor's signature　　　24 / 03 / 06

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Sudha Tonggamnerd
November 2005

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LIST OF ABBREVIATIONS

A/C	=	Aircraft
ACGIH	=	American Conference of Governmental Industrial Hygienists
ARFF	=	Aircraft Rescue and Five Fighting
ATA	=	Air Transport Association
BFE	=	Buyer-Furnished Equipment
CAA	=	Civil Aviation Authority
CMM	=	Component Maintenance Manual
COTS	=	Commercial Off-The-Shelf
EMLT	=	Exponential Model for Life Testing
FAA	=	Federal Aviation Administration
FE/DE	=	Fire Emulator / Detector Evaluator
FIM	=	Fault Isolation Manual
Flt.	=	Flight
IAFPSWG	=	International Aircraft Fire Protection Systems Working Group
IAT	=	International Aero Technologies
MPS	=	Minimum Performance Standard
MTTF	=	Mean-Time-To-Failure
NASA	=	National Aeronautics and Space Administration
NIOSH	=	National Institute for Occupational Safety and Health
NIST	=	National Institute of Standards and Technology
NTIS	=	National Technical Information Service,
NTFB	=	National Transportation Safety Board
ppmw	=	parts per million by weight (of liquid)
ppmv	=	parts per million by volumes (of air)
PNN	=	Probabilistic Neutral Network
PSI	=	Pound Square Inch
OSD	=	Optical Smoke Detector
OSHA	=	Occupational Safety and Health Administration
STA	=	Station, (means location or position that located)
TTD	=	Time-To -Detection

DESIGN OF EARLY WARNING FIRE DETECTION (EWFD) PROTECTION IN AIRCRAFT CARGO COMPARTMENTS

INTRODUCTION

Commercial transport aircraft cargo compartments require both fire detection and suppression capabilities in order to meet regulatory requirements. Historically, while there have been few fires reported in cargo compartments, **false alarms** are a much more frequent event. A recent study places the false alarm to smoke detection ratio at 200:l over the last five years. A significant fraction of false alarms is thought to be due to nuisance sources such as condensed water vapor, and other aerosol sources.

The Federal Aviation Administration requires that detectors meet standards in SAE AS 8036 (wherein UL smoke box testing is referenced as appropriate to check alarm sensitivity) which specifies that the alarm must fall between 60 %/flight to 96 %/flight light transmission (extinction coefficients between 3.0 m^{-1} to 0.13 m^{-1}).

Each new cargo compartment design must pass a system test on the ground and in-flight using "smoke" which may be produced from aerosol generators, tobacco smoldering or other non-fire sources. An alarm must be recorded within 60 s of the start of the aerosol source.(appendix)

In order to better understand the reasons for the current high false fire alarm ratio in Aeronautic Applications, an analysis of actual fire and false alarm events has been conducted using different database. Last research (funded by the European Commission within the 5th Framework Program Fire DetEx) included the 3-following analysis and also in this research will be review of false fire alarm case, to the real fire alarm case and the fire detection system can only be improved on the basis of clear performance objectives,

Analysis of False Alarm Cases

A review of false fire alarm cases extracted from different database will be presented, for some typical case, it will be analyzed whether the alarm was triggered by a system malfunction, particular environmental conditions or by the detection of aerosol particles.

Analysis of Fire Alarm Cases

Real fire alarm cases will also be considered, it will be determined what was the probable fire source, which phenomena has likely caused the ignition and what should have been the best fire sensor under these conditions.

Definition of Fire and Non-Fire Scenario

The fire detection system can only be improved on the basis of clear performance objectives, fire and non-fire scenario will be presented against which the performance of new fire detection concept can be measured and evaluated. The Early Warning Fire Detection (EW/FD) prototype Series 1, tests conducted EW/FD prototype 2 demonstrated slightly better performance and faster response times than the Simplex COTS (commercial off-the-shelf) smoke detection system.

The FAA is developing standard flaming fire and smoldering fire sources that will be more repeatable than the range of aerosol sources currently in use, and that will allow other types of detectors besides smoke detectors to be qualified. In a recent survey of fire detection technologies, gas and thermal sensing were identified as plausible additions to particulate sensing in cargo compartments to improve detection.

The selection of the flaming, smoldering, and nuisance alarm scenarios was guided by a desire to cover a range of potential fire and nuisance alarm scenarios that would each progress to a point were current aircraft detectors would alarm; there was no basis for these scenarios from statistical analysis of fire data, nor service difficulty reports addressing false alarms.

The results of the Early Warning Fire Detection (EW/FD) prototype Series 1, tests conducted on the ex-USS Shad well over the period of February 7-18, 2000. Four EW/FD prototypes were successfully integrated with a data acquisition system to operate in real time using a probabilistic neutral network (PNN) and provided appropriate alarms in real time. Two prototypes were evaluated consisting of different sets of sensors and a PNN based on previous work in this program. EW/FD prototype 2 demonstrated slightly better performance than EW/FD prototype 1 and faster response times than the Simplex COTS (commercial off-the-shelf) smoke detection system. Even EW/FD prototype 1 demonstrated on average faster response times than the Simplex detectors.

A second series of tests was conducted to evaluate and improve the multivariate data analysis notebooks and candidate sensor suites used for the Early Warning Fire Detection (EW/FD) system under development. The EW/FD system is to provide reliable warning of actual fire conditions in less time with fewer nuisance alarms than commercially available smoke detection systems. Tests were conducted from 25 April to 5 May 2000 onboard the ex-USS SHADWELL. This report documents the performance of the probabilistic neural network achieved in real- time during this test series. Further optimization of the algorithm has yielded performance gains over the real-time results. Modifications have been made that improve the real-time data acquisition and the ion sensor calibration. Background subtraction was investigated and will be used in future tests. The best performance was provided by a four-sensor array consisting of ionization, photoelectric carbon monoxide and carbon dioxide sensors.

Objective

1. To Study

The objective of this study is to improve fire detection, fire and nuisance scenarios were emulated in the Fire Emulator/Detector Evaluator (FE/DE), and gas, thermal and particulate sensor signals were gathered to determine potential sensor combinations that would overcome various Schematic of Fire Emulator / Detector Evaluator.

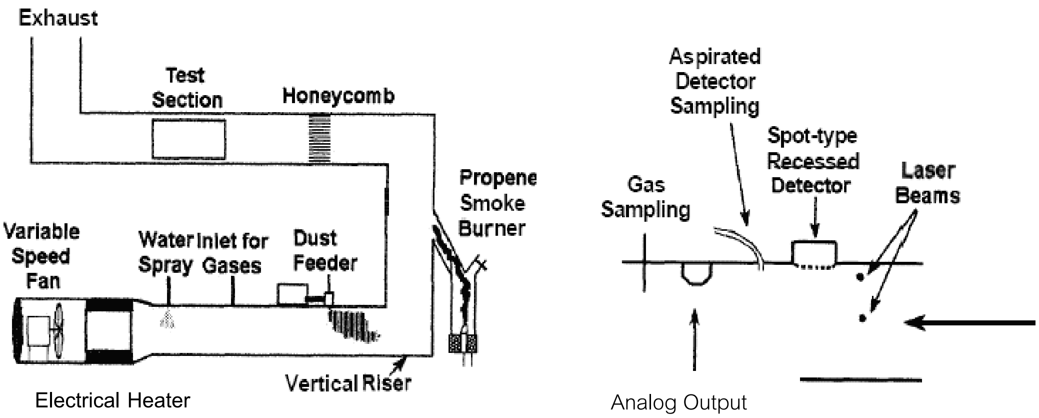


Figure 1 Schematic of Fire Emulator / Detector Evaluator (FE/DE),
(Test Section Side View)
Source: Cleary and Donnelly (2001)

(FE/DE) nuisance alarm events in aircraft cargo compartments. Guide to study to modify false alarm events were often considered unexplainable or attributed to a system malfunction whereas a better knowledge of these conditions would have led to a different classification.

The oil mist aerosol was generated by mobilizing cooking oil from a bank of 10 medical inhalant nebulae's located at the bottom of the vertical riser of the FE/DE. This aerosol is a surrogate for hydraulic oil or non-volatile mists introduced in a cargo compartment intentionally (cargo treatment) or unintentionally. The fan speed was set at 7 Hz yielding at mean flow velocity of 0.15 *m/s* at the test section.

Overall objectives – There is no single physical parameter that would allow the detection of this wide fire spectrum with an evenly distributed sensitivity under these conditions, in the currently used systems, the smoke detectors have to be adjusted so as to early detect the fire type for which their sensitivity is basically the worst (and to meet the certification requirements making them also more sensitive to environmental conditions.

Basically, a combination of several criteria to trigger a fire alarm would bring a significant benefit in terms of discrimination capabilities, provided of course that the fire and non-fire situations are well known. Therefore in order to improve significantly the fire detection reliability, it is necessary to better understand, under this environment, the physical parameters that distinguish the start of a fire from those that are due to non-dangerous phenomenon.

2. To Develop Fire Detection Systems Design

These Fire Detection Systems are perfectly adapted to extremely vulnerable cargo areas for the protection of cargo compartments of passenger and freighter aircraft, where the access in flight is not possible and where a system that significantly reduces the risk of spurious warnings is an essential requirement. We just offer dual loop Fire Detection Systems modification which is increase the systems integrity and reliability not up 4-componet that they are too high cost of investment, for over long periods of useful life as following reasonable details.

2.1 Component Failure Rates

The model used to develop component failure rates was the Exponential Model for Life Testing (EMLT).13 The EMLT model defines the estimate of the mean life (λ) of a component as (2)

Where Tr = accumulated time on test, and
r = number of component fires.

The confidence interval about the mean is given by (3) where is dependent on the degrees of freedom (DF) and found in statistical tables, and

$$DF = 2(r). \quad (1)$$

Most system elements have fault rates (λ = **1/MTBF**) that are constant (λ = **0**) over long periods of useful life. During these periods, faults occur at random times.

2.2 Mean-time-between-failure (MTBF)

A common use of the failure rate is to determine the mean-time-between-failure (MTBF), which may be thought of as the "average" time between failures. (This assumes that the system is "renewed", i.e. fixed, after each failure, and then returned to service.)

A common misconception about the MTBF is that it specifies the time (on average) when half of the items will fail. This is only true for certain symmetrical distributions. In many cases, such as the non-symmetrical exponential distribution, this is not true. For example, for an exponential failure distribution, the probability that an item will fail by the MTBF is approximately 0.63. Also, MTBF is a statistic and, therefore, not suitable for predicting the time to failure for an individual component (or system) due to inherent variability and the particular use of the component (or system.)

Formal definition, the MTBF is simply the reciprocal of the failure rate,

$$MTBF = \frac{1}{\lambda}. \tag{2}$$

The MTBF is often denoted by the symbol, θ , or,

$$MTBF = \theta \tag{3}$$

Since failure rate and MTBF are simply reciprocals, both notations are found in the literature depending on which notation is most convenient for the application.
The MTBF can be defined in terms of the expected value of the failure density function,

$$MTBF = E(t) = \int_0^\infty x f(x)\, dx \tag{4}$$

2.3 Failure rate

A failure rate is the average frequency with which something fails. Failure rate, often denoted by the Greek letter λ (lambda), is important in reliability theory. The failure rate depends on the failure distribution, which describes the probability of failure prior to a specified time. Another way of expressing failure rate is the mean time between failure (MTBF), which is the "average" time between failures. The failure rate is not always constant, so the hazard function is used to describe the instantaneous failure rate at any point in time.

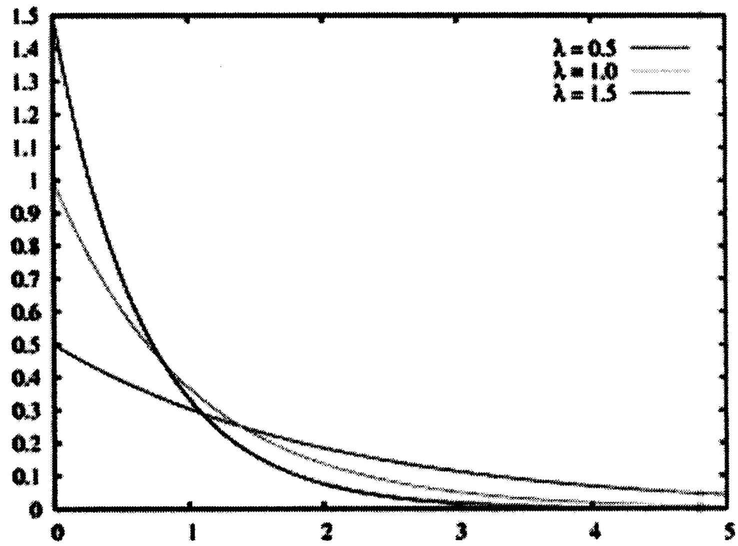


Figure 2 Exponential Failure Density Functions
Source: Wikipedia encyclopedia

Variations of MTBF

There are many **variations** of MTBF, such as mean-time-between-system-abort (MTBSA) or mean-time-between-critical-failure (MTBCF). Such nomenclature is used when it is desirable to differentiate among types of failures. For example, in an automobile, the failure of the FM radio does not prevent the primary operation of vehicle, so that it may be desirable to differentiate the failure rates of critical versus non-critical failures. **Mean-time-to-failure (MTTF)** is sometimes used instead of MTBF in cases where a system is replaced after a failure, whereas MTBF denotes time between failures where the system is repaired. The **Failures In Time (FIT)** rate of a device is the number of failures that can be expected in one billion (10^9) hours of operation. This term is used particularly by the semiconductor industry.

Problems with MTBF

As of 1995, the use of MTBF in the aeronautical industry (and others) has been called into question due to the inaccuracy of its application to real systems and the nature of the culture that it engenders - many component MTBFs are given in databases, and often these values are very inaccurate; its use has led to the negative exponential distribution being used much more than it should have been - it has been estimated that only 40% of components have failure rates described by this; it has also been corrupted into the notion of an "acceptable" level of failures, which removes the desire to get to the root cause of a problem and take measures to erase it. The British Royal Air Force is looking at other methods to describe reliability, such as Maintenance Free Operating Period (MFOP).

Hazard function

One drawback of the MTBF is that it assumes that the failure rate is constant for all intervals. However, the failure rate of a system may vary with time, such that a single number does not accurately describe the failure rate during all intervals of time. For example, as an automobile grows older, the failure rate in its 5th year of service may be greater than its failure rate during its 1st year of service, so that it is not desirable to use the same failure rate to describe both of these intervals of time. By calculating the failure rate for smaller and smaller intervals of time, Δt, the interval becomes infinitesimally small. This results in the **hazard function,** which is the **instantaneous** failure rate at any point in time,

$$h(t) = \lim_{\Delta t \to 0} \frac{R(t) - R(t + \Delta t)}{\Delta t \cdot R(t)}$$

, or

$$h(t) = \frac{f(t)}{R(t)}. \qquad (4)$$

If the hazard function is constant, then the failure rate is the same for any equal period of time. This implies that failures occur with equal frequency during any equal period of time. The exponential failure distribution has a constant hazard rate. For other distributions, such as the Weibull distribution or the log-normal distribution, the hazard function is not constant, which means that the failure rate varies with time.

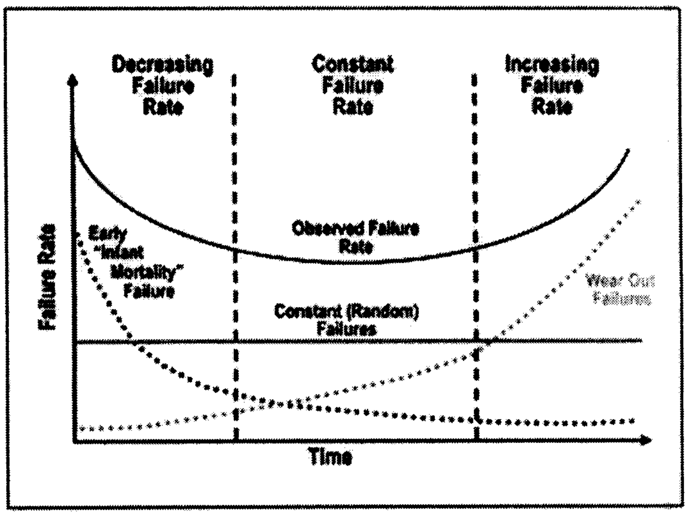


Figure 3 The "bathtub" Curve Hazard Function
Source: Wikipedia encyclopedia

The **bathtub curve** describes a particular form of the hazard function that comprises three parts:

The first part is a decreasing failure rate, known as early failures or **infant mortality**.

The second part is a constant failure rate, known as random failures.

The third part is an increasing failure rate, known as wear-out failures.

The bathtub curve is often employed to represent the failure rate of a product during its lifecycle, namely, the product experiences early ″infant mortality″ failures when first introduced, then exhibits random failures with constant failure rate during its ″useful life″, and finally experiences ″wear out″ failures as the product exceeds its design lifetime.

The bathtub curve is often modeled by a piecewise set of three hazard functions, While the bathtub

$$h(t) = \begin{cases} c_0 - c_1 t + \lambda, & 0 \leq t \leq c_0/c_1 \\ \lambda, & c_0/c_1 < t \leq t_0 \\ c_2(t - t_0) + \lambda, & t_0 < t \end{cases} \tag{5}$$

curve is useful, not every product or system follows a bathtub curve hazard function.

Failure rate data

Failure rate data can be obtained in several ways. The most common means are:

Historical data about the device or system under consideration. Many organizations maintain internal databases of failure information on the devices or systems that they produce, which can be used to calculate failure rates for those devices or systems. For new devices or systems, the historical data for similar devices or systems can serve as a useful estimate. Government and commercial failure rate data. Handbooks of failure rate data for various components are available from government and commercial sources. Reliability Prediction of Electronic Equipment, is a military standard that provides failure rate data for many military electronic components. Several failure rate data sources are available commercially that focus on commercial components, including some non-electronic components.

Testing

The most accurate source of data is to test samples of the actual devices or systems in order to generate failure data. This is often prohibitively expensive or impractical, so that the previous data sources are often used instead.

Units

Failure rates can be expressed using any measure of time, but **hours** is the most common unit in practice. Other units, such as miles, revolutions, etc., can also be used in place of "time" units. Failure rates are often expressed in engineering notation as failures per million, or 10^{-6}, especially for individual components, since their failure rates are often very low.

Example

Suppose it is desired to estimate the failure rate of a certain component. A test can be performed to estimate its failure rate. Ten identical components are each tested until they either fail or reach 1000 hours, at which time the test is terminated for that component. (The level of statistical confidence is not considered in this example.) The results are as follows:

Failure Rate Calculation Example

Component	Hours	Failure
Component 1	1000	No failure
Component 2	1000	No failure
Component 3	467	Failed
Component 4	1000	No failure
Component 5	630	Failed
Component 6	590	Failed
Component 7	1000	No failure
Component 8	285	Failed
Component 9	648	Failed
Component 10	882	Failed
Totals	7502	6

Additive

Under certain engineering assumptions, the failure rate for a complex system is simply the sum of the individual failure rates of its components, as long as the units are consistent, e.g. failures per million hours. This permits testing of individual components or subsystems, whose failure rates are then added to obtain the total system failure rate.

Estimated failure rate is,

$$\frac{6 \text{ failures}}{7502 \text{ hrs}} = 0.0007998 \text{ failures/hr} = 799.8 \text{ x } 10^{-6} \text{ failures/hr}$$

,or 799.8 failures for every million hours of operation.

Confidence interval

In statistics, a confidence interval (CI) is an interval between two numbers, where there is a certain specified level of confidence that a population parameter lies. Confidence intervals are the most prevalent form of interval estimation.

If *U* and *V* are statistics (i.e., observable random variables) whose probability distribution depends on some unobservable parameter θ, and

$$\Pr(U < \theta < V) = x \qquad (6)$$

(where x is a number between 0 and 1) then the random interval (*U*, *V*) is a "(100·x)% confidence interval for θ ". The number x (or 100·x%) is called the confidence level or confidence coefficient. In modern applied practice, almost all confidence intervals are stated at the 95% level.

Concrete practical example

Here is one of the most familiar realistic examples. Suppose X_1, ..., X_n are an independent sample from a normally distributed population with mean μ and variance σ^2.

$$\overline{X} = (X_1 + \cdots + X_n)/n, \tag{7}$$

$$S^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2. \tag{8}$$

Then

$$T = \frac{\overline{X} - \mu}{S/\sqrt{n}} \tag{9}$$

Let has a Student's t-distribution with $n - 1$ degrees of freedom. Note that what distribution T has does not depend on the values of the unobservable parameters μ and σ^2; i.e., it is a *pivotal quantity*. If c is the 95th percentile of this distribution, then

$$\Pr(-c < T < c) = 0.9. \tag{10}$$

(Note: "95th" and "0.9" are correct in the preceding expressions. There is a 5% chance that T will be less than −c and a 5% chance that it will be larger than +c. Thus, the probability that T will be between −c and +c is 90%.)

Consequently

$$\Pr\left(\overline{X} - cS/\sqrt{n} < \mu < \overline{X} + cS/\sqrt{n}\right) = 0.9 \tag{11}$$

and we have a 90% confidence interval for μ.

How to understand confidence intervals

Confidence levels are typically given alongside statistics resulting from sampling.

In a statement: we are 95% confident that between 35% and 45% of voters favor Candidate A, 95% is our confidence level and 35%-45% is our confidence interval. It is very tempting to misunderstand this statement in the following way. We used capital letters *U* and *V* for random variables; it is conventional to use lower-case letters *u* and *v* for their observed values in a particular instance. The misunderstanding is the conclusion that

$$\Pr(u < \theta < v) = 0.9, \tag{12}$$

so that after the data has been observed, a conditional probability distribution of θ, given the data, is inferred. For example, suppose *X* is normally distributed with expected value θ and variance 1. (It is grossly unrealistic to take the variance to be known while the expected value must be inferred from the data, but it makes the example simple.) The random variable *X* is observable. (The random variable *X* - θ is *not* observable, since its value depends on θ .) Then *X*- θ is normally distributed with expectation 0 and variance 1; therefore

$$\Pr(-1.645 < X - \theta < 1.645) = 0.9. \tag{13}$$

Consequently

$$\Pr(X - 1.645 < \theta < X + 1.645) = 0.9, \tag{14}$$

so the interval from *X* -1.645 to *X* + 1.645 is a 90% confidence interval for θ. But when *X* = 82 is observed, can we then say that

$$\Pr(82 - 1.645 < \theta < 82 + 1.645) = 0.9 \ ?$$

This conclusion does not follow from the laws of probability because θ is not a "random variable"; i.e., no probability distribution has been assigned to it. Confidence intervals are generally a frequentist method, i.e., employed by those who interpret "90% probability" as "occurring in 90% of all cases". Suppose, for example, that θ is the mass of the planet Neptune, and the randomness in our measurement error means that 90% of the time our statement that the mass is between this number and that number will be correct. The mass is not what is random. Therefore, given that we have measured it to be 82 units, we cannot say that in 90% of all cases, the mass is between 82 -1.645 and 82 + 1.645. There are no such cases; there is, after all, only one planet Neptune.

But if probabilities are construed as degrees of belief rather than as relative frequencies of occurrence of random events, i.e., if we are Bayesians rather than frequentists, can we then say we are 90% sure that the mass is between 82 -1.645 and 82 + 1.645? Many answers to this question have been proposed, and are philosophically controversial. The answer will not be a mathematical theorem, but a philosophical tenet. Less controversial are Bayesian credible intervals, in which one starts with a prior probability distribution of θ , and finds a posterior probability distribution, which is the conditional probability distribution of θ given the data.

For users of frequentist methods, the explanation of a confidence interval can amount to something like: "The confidence interval represents values for the population parameter for which the difference between the parameter and the observed estimate is not statistically significant at the 10% level". Critics of frequentist methods suggest that this hides the real and, to the critics, incomprehensible frequentist interpretation which might be expressed as: "If the population parameter in fact lies within the confidence interval, then the probability that the estimator either will be the estimate actually observed, or will be closer to the parameter, is less than or equal to 90%". Users of Bayesian methods, if they produced a confidence interval, might by contrast say "My degree of belief that the parameter is in fact in the confidence interval is 90%". Disagreements about these issues are not disagreements about solutions to mathematical problems. Rather they are disagreements about the ways in which mathematics is to be applied.

2.4 Failure rate definitions

Failure rate can be defined as,The total number of failures within an item population, divided by the total time expended by that population, during a particular measurement interval under stated conditions. (MacDiarmid, et al.) An example is provided in a later section.

Failure rate can also be defined mathematically as the conditional probability per unit time that a failure occurs in a specified interval, given no failure before time t . This is often written in terms of the reliability function, $R(t)$, as,

$$\lambda = \frac{R(t_1) - R(t_2)}{(t_2 - t_1) \cdot R(t_1)},$$

or,

$$\lambda = \frac{R(t) - R(t + \triangle t)}{\triangle t \cdot R(t)} \tag{15}$$

where, t_1 and t_2 , and are the beginning and ending of a specified interval of time, and $R(t)$ is the reliability function, i.e. probability of no failure before time t.

Note that this is a conditional probability, hence the $R(t)$ in the denominator.

2.5 Failure Distributions

Failure rate depends on its failure distribution, $F(t)$, which is a cumulative distribution function that mathematically describes the probability of failure prior to time t ,

$$P(\mathbf{t} \leq t) = F(t), t \geq 0. \tag{16}$$

The failure distribution function is the integral of the failure *density* function, $f(x)$,

$$F(t) = \int_0^t f(x)\,dx \quad . \tag{17}$$

There are many failure distributions (*see List of important probability distributions*). A common failure distribution is the **exponential failure distribution,**

$$F(t) = \int_0^t \lambda e^{-\lambda x}\,dx = 1 - e^{-\lambda t} \quad , \tag{18}$$

which is based on the exponential density function. In this case, the parameter λ in the exponential distribution is the **failure rate.**

2.6 Aircraft Fire Detection

The luggage and cargo compartments under the floor are now required to be equipped with fire detectors and extinguishers. One of the major challenges of fire detection in cargo compartments is the minimization of false alarms. The current detectors being used in aircraft cargo bays use either photoelectric or ionization sensors to detect the smoke particles produced by a fire. While smoke detectors work well at detecting the presence of fire, they can be fooled by the presence of other particles, such as dust, fog and other aerosols that sometimes form in the cargo compartments. It has been estimated that as many as 200 false alarms occur for every actual fire. In-flight fires are relatively rare events. However, there are no provisions for the pilot or crew to verify the presence of a fire in the under-floor cargo compartment. Any alarm has to be treated as an actual fire, forcing the pilot and crew to follow emergency procedures, such as landing at the nearest airport, discharging extinguishing equipment, etc.

2.7 Reliability Calculation

- Fire and nuisance alarm scenarios for aircraft cargo compartments were reproduced in the FE/DE.

- Between fire and non-fire conditions, data gathered contains articulate, combustion gas and temperature rise values that may be used to identify Sensor / from the following design, the specified component must be collected to this methodology is the cheapest cost of The detector part number; Autronics 2156-556, component cost is 999.60 US$ per each.

From those data and part catalog we can verify the detection ratio value (1).

(Q) = (1/200) = 0.005 (Component Unreliability) **(1)**

1. Connection 1; All detectors which were designed and installed in the both forward and aft compartment. (all 9-position)

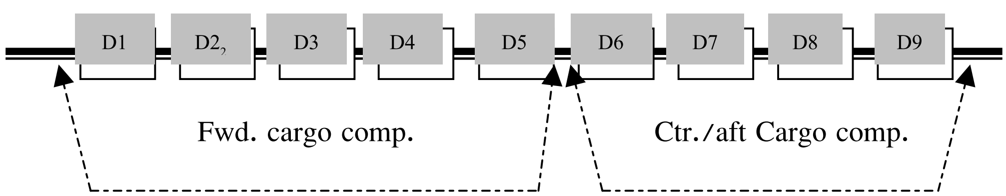


Figure 4 Series Connection Simple Diagram

From simple block diagram is for 9- detector in the example commercial aircraft which is designed, 5 in the forward cargo compartment under cabin passengers floor and 4-detector installed in the center/aft cargo compartment

$Qs = 1-(1-Q_1)(1-Q_2)(1-Q_3)(1-Q_4)(1-Q_5)(1-Q_6)(1-Q_7)(1-Q_8)(1-Q_9)$ (2)

Where; Qs is Unreliability of system

Q_n is Unreliability of sensor (n); n = 1, 2, 3, 4, 5, 6, 7, 8 up to 9-position.

$Rs = 1 - Qs$ **(3)**

Where; Rs is System Reliability ;

By substitution in Q- value of Detection ratio into no. 1 - 9 in (2)

Then;

Qs = 1 - {(1-0.005) (1-0.005) (1-0.005) (1-0.005) (1-0.005) (1-0.005) (1-0.005) (1-0.005) (1-0.005)}

Qs = 1 - $(0.995)^9$

Qs = 1 - 0.955889

Qs = 0.044111

To substitute Qs- value into (3) to compute the value of Rs of this system, then;

Rs = 1 - 0.044111

Rs = 0.955889

2. Connection 2; To double Detectors as parallel diagram in the previous series configuration to all designed detectors.

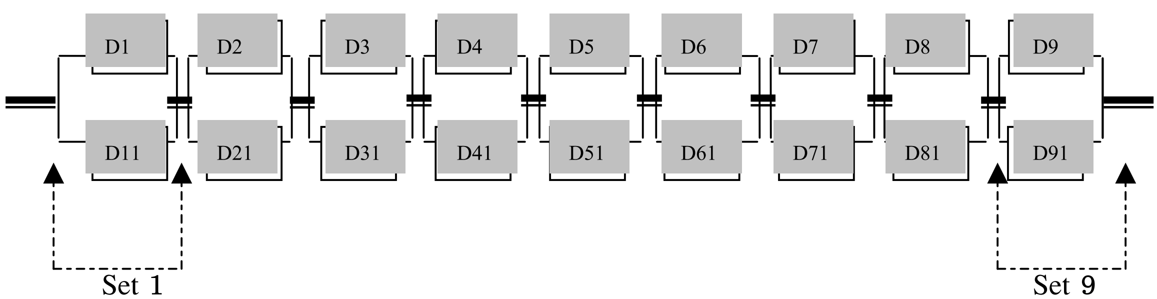


Figure 5 Double Detectors (parallel) Diagram Connection in the Previous Series Configuration

Parallel condition, (System is in good condition) ; according to reliability computing formula

$$\mathbf{Rp = 1 - Q_A Q_B} \qquad (4)$$

Note ; all Rp- values are equal, then only one detector let considered to compute.

In set ; Rp = 1 − (0.005)(0.005) = 0.999975 (reliability in parallel each set)

or Q = 1 − 0.999975 = 0.000025 (Component Unreliability)

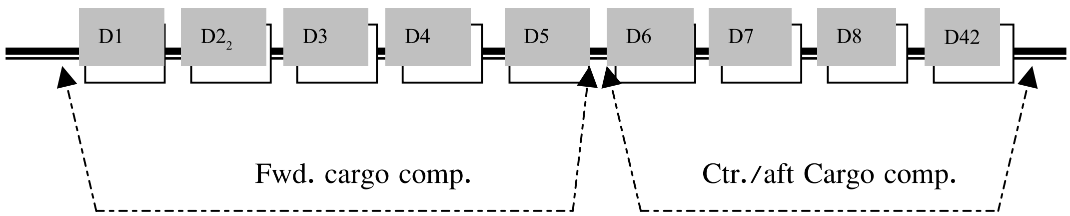


Figure 6 Double Detectors (components) Series Connection Simple Block Diagram

When Q-value = 0.000025

To compute the new R

$$\mathbf{Qs = 1 - (1 - 0.000025)^9} \qquad (5)$$

$$Qs = 1 - (0.999975)^9$$

$$Qs = 1 - 0.99977$$

Qs = 0.00023 System Unreliability

from **(3); Rs = 1 − Qs** **(6)**

Rs = 1 − 0.00023 = 0.99977 System Reliability

The following simplified (figure 7) where illustrate parts location connection with 2-component, detectors connection as parallel diagram in each section as previous series configuration to all designed detector components.

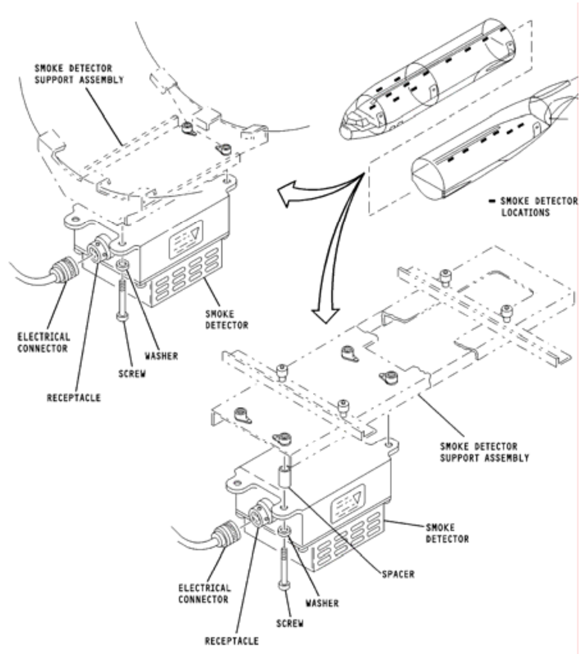


Figure 7 Double Components Connection (designed view)

Source: MD-11AIRCRAFT FIM MANUAL 26 - 15 - 00 Page 103 Jul 1/01

3. Connection 3; To tipple detectors connection as parallel diagram in the previous series configuration to all designed detector components

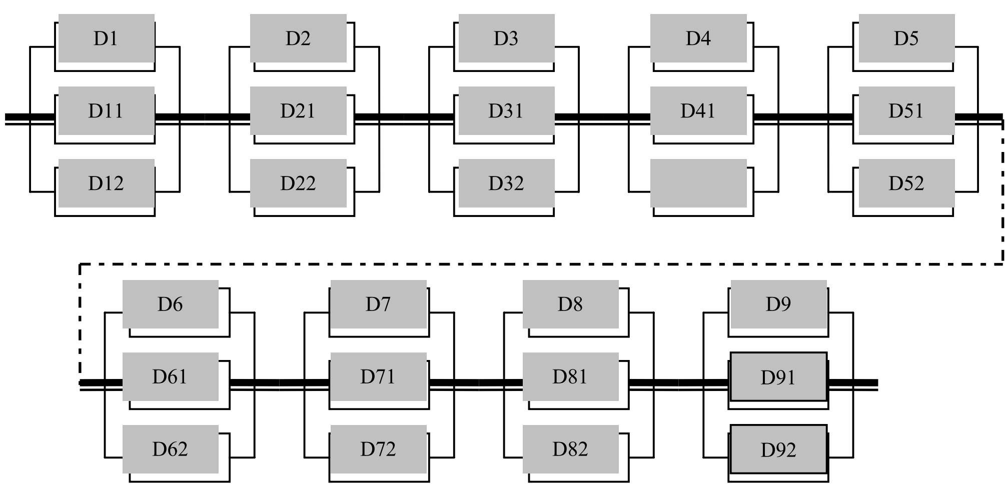


Figure 8 Tipple Connection (Parallel diagram) Connection

Rp = (reliability in parallel each set), From ;

$$\mathbf{Rp = 1 - Q_A Q_B Q_C} \tag{7}$$

All set, Rp values are equal, only one detector has to be considered to compute then,

Rp, set 1(to be simplified as D1 according to figure 9)

= 1 – (0.005)(0.005)(0.005)

= 0.999999875

Or **Q = 1 – 0.999999875 = 0.000000125**

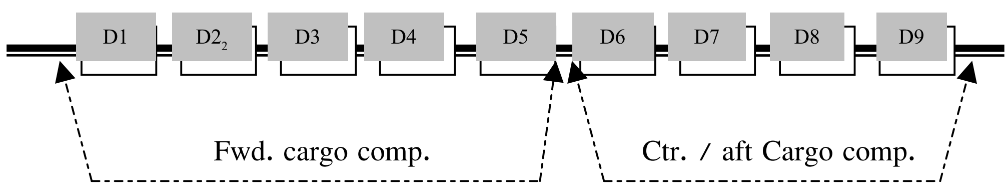


Figure 9 New Simple Tipple Detectors Connection Drawing (from figure 8)

When each Q-value = 0.000000125

To compute the new R, with n = 9

Qs = $1 - (1 - 0.000000125)^9$

Qs = $1 - (0.999999875)^9$

Qs = 1 – 0.999998875

Qs = 0.000001125 System Unreliability

Rs = 1 – 0.000001125 = 0.999998875 System Reliability

4. Connection 4; Two-pair of detectors connection as parallel diagram in the previous series configuration to all designed detector components.

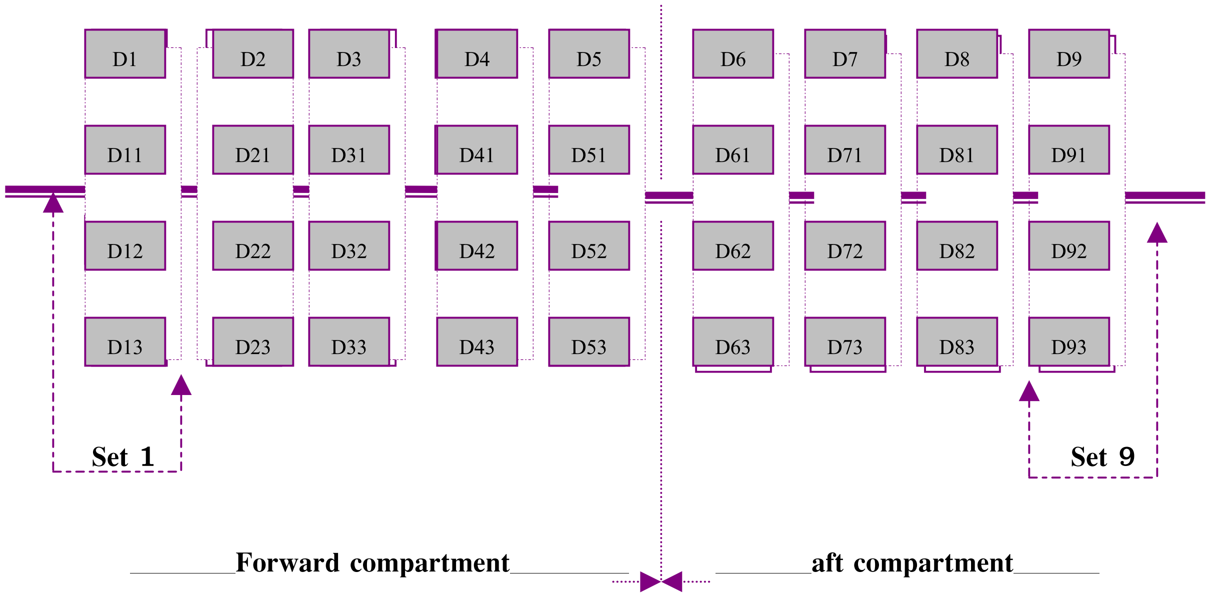


Figure 10 Two-pair Connection,4 in Parallel with 9-Location in both forward and aft Compartments (Parallel diagram) Connection

Rp = (reliability in parallel each set), From ;

Rp = 1 − $Q_A Q_B Q_C Q_D$ (9)

All set, Rp values are equal, only one detector has to be considered to compute then, Rp, set 1(to be simplified as D1 according to figure 11)

= 1 − (0.005)(0.005)(0.005) (0.005)

= 0.999999994375

(Rs) System Reliability with 9-Component in series = 0.999999994375

And **Q** = 1 − 0.999999994375 = **0**, refer Exel program computing and Delphi programming graphic values.

Qn = 0.005, Unit Cost = 999.6

	Qs	Cost	Reliability (Rs)
Type A	0.04411042	8996.4	0.95588958
Double	0.000224978	17992.8	0.999775022
Tipple	0.000001125	26989.2	0.999998875
Two Pairs	0.000000005625	35985.6	0.999999994375

Note: component type A (general component, part number Autronics 2156-556)

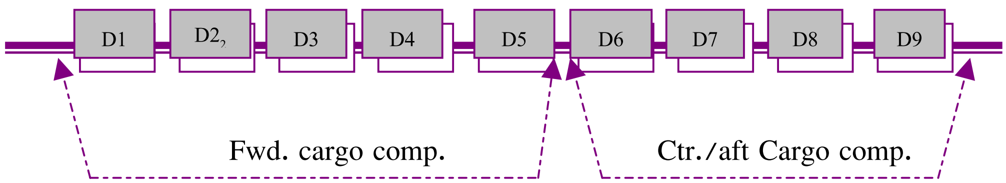


Figure 11 New Simple of Two-pair Connection,4 in Parallel with 9-Location in both forward and aft Compartments.

2.8 **Decision Making**

1. Reliability Acceptance:

By (4), (9) we can make decision to start investment budget with probability reliability calculation system could be placed at the probability diagram in the previous series configuration 2-parallel connection is saver than the others with the reliability = **0.999975,** that it is mean suitable acceptability to this design but according to computerized, DELPHI program which is flexible by programming comply the final optimize display is using component type A with 4-in parallel with the reliability = **0.999999994375.** It is interesting for investment decision design of this aircraft cargo compartment fire detection protection modification while authorized personnel making decision or optimum to modify (reliability reaches 1, in any types of operating commercial aircrafts and concerning with authorized wiring diagram and FAA approval.

2. Cost of maintenance:

We can study before retrofit or developing of all the detectors in any aircraft types according to basic data given , which several connection with detectors part number; Autronics 2156-556 as following details.

Detector (Autronics 2156-556) , price 999.60 US$ / each
With 9 Detectors, cost of investment = 8,996.4 US$ per system, Reliability = 0.955889
18 Detectors, cost of investment = 17,992.8 US$ per system, Reliability = 0.99977
If 27 Detectors, cost of investment = 26,989.2 US$ per system, Reliability = 0.999998875
But 36 Detectors, cost of investment = 35,985.6 US$ per system, Reliability =
= 0.999999994375 (almost =1) with optimum designed

Relationship between the reliability values and cost of maintenance (cost of component investment) can be complied by computer program and plot graph (chart) by MS-EXEL as the following simplified display.

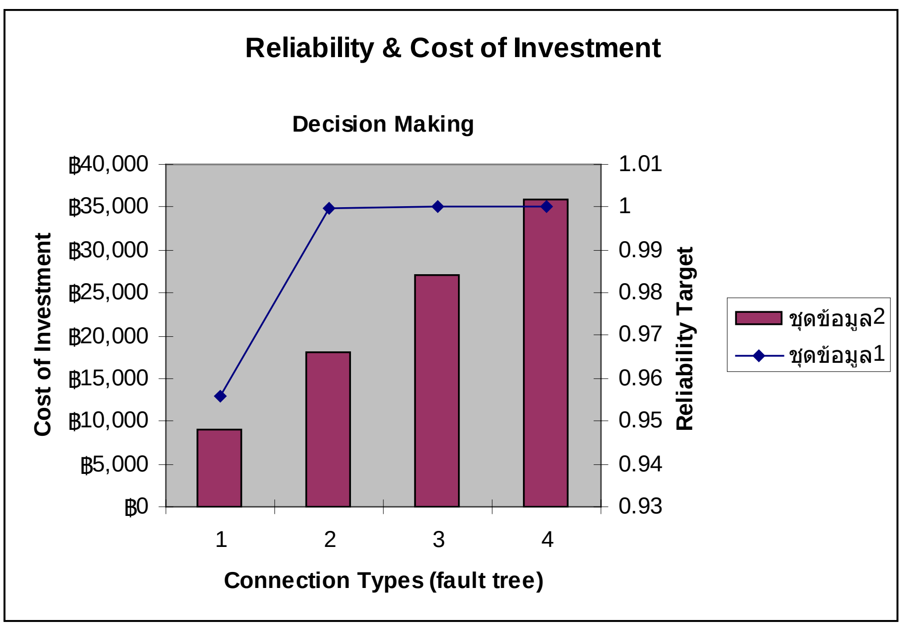


Figure 12 Relationship between Reliability& Cost of Component
Source: Graphic calculated from Exel program

From simplified chart above, money has to be expensed more where modification start to double connection (17992.8 US$ expensed and 26989.2 US$ where tipple tree there are more invest if need to be connected with two-pair of detectors 4- connection but the target, reliability reaches 1 optimum) decision making might be considered complied with reliability required (start the same high value probability almost 1 indicated.

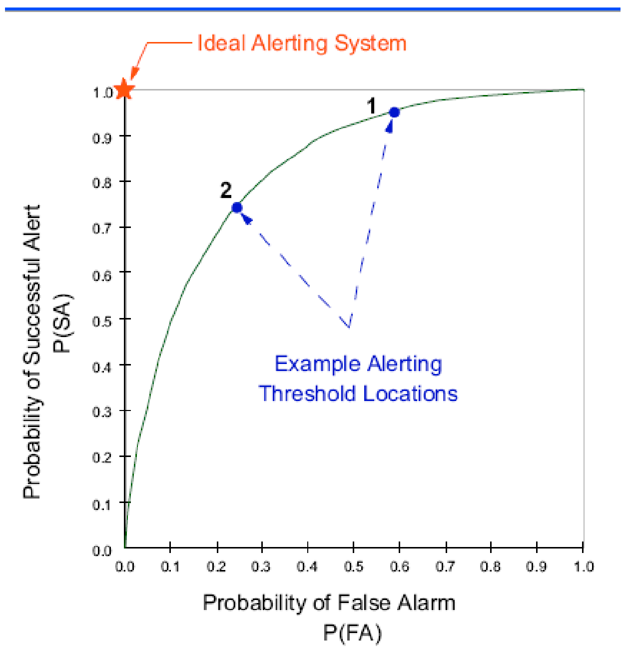


Figure 13 Probability of False Alarm

Source: Wikipedia encyclopedia

Use "figures of merit" to examine trade-offs applicable to application

- Time-To -Detection (TTD) of alert of true non-conformance
- False Alarm (FA) of alert when actually conforming
- FA/TTD tradeoff analogous to inverse System Operation Characteristic curve

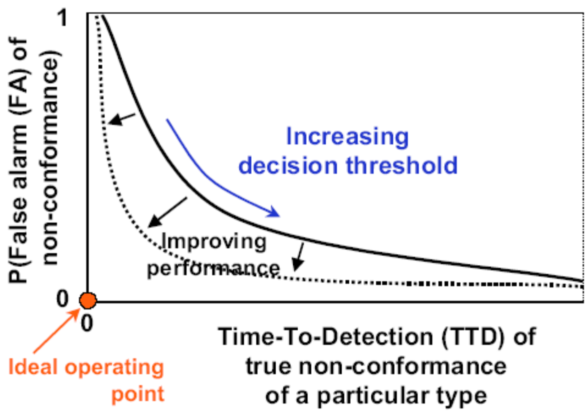


Figure 14 Figure of Merit

Source: Wikipedia encyclopedia

3. Cost Benefit Analysis :

The result is cost efficient systems with enhanced capabilities in terms of maintainability and low cost of ownership. Method that preventing fire on commercial aircraft, helping airlines save money, improving safety, ensuring compliance and greatly reduce on-ground delays. Many of the world's major airline carriers, have been recognized by airline executives, engineers, pilots, maintenance crews and industry analysts for their superior technology, ease of installation, and rapid return on investment. Solutions use state-of-the-art technologies to remove the ever-present threat of fire on commercial aircraft improve airline safety, ensure compliance with FAA regulations and greatly reduce delays, thereby enabling airlines to focus on faster turns and use their aircraft more efficiently. On the ground and in the air, commercial aircraft more cost effective to operate and safer to fly.

LITERATURE REVIEW

Rose Pehrsson, et al. (2000). Who explained in the Real-Time Probabilistic Neural Network Performance and Optimization for Fire Detection and Nuisance Alarm Rejection: the Early Warning Fire Detection (EWFD) system under development, system is to provide reliable warning of actual fire conditions in less time with fewer nuisance alarms than commercially available smoke detection systems. Tests were conducted the performance of the probabilistic neural network achieved in real- time during this test series. Further optimization of the algorithm has yielded performance gains over the real-time results. Modifications have been made that improve the real-time data acquisition and the ion sensor calibration. Background subtraction was investigated and will be used in future tests. The best performance was provided by a four sensor array consisting of ionization, photoelectric carbon monoxide and carbon dioxide sensors.

Daniel T. Wong et al. (2000). Who explained in the Prototype Early Warning Fire Detection System: Test Series 1 Results 2000, this report documents the results of the Early Warning Fire Detection (EWFD) prototype Series I tests conducted on the four EWFD prototypes were successfully integrated with a data acquisition system to operate in real time using a probabilistic neural network (PNN) and provided appropriate alarms in real time. Two prototypes were evaluated consisting of different sets of sensors and a PNN based on previous work in this program. EWFD prototype 2 demonstrated slightly better performance than EWFD prototype1 and faster response times than the Simplex COTS smoke detection system. Even EWFD prototype 1 demonstrated on average faster response times than the Simplex detectors.

Wright Mark T. et al. (2000). Who studied in the Prototype Early Warning Fire Detection System: Test Series 3 Results 2001, This work is a continuation of a multi-year effort to develop an early-warning fire detection system (EWFD) that is immune to nuisance alarms. Over the past two years, efforts have focused on identifying appropriate sensors and candidate multivariate alarm algorithms. The results of this test series have demonstrated improved performance of the current probabilistic neural networks (PNN) alarm algorithm compared to previous prototype designs as well as alternate sensor/PNN combinations evaluated in this work. The current alarm algorithm resulted in better overall performance than the commercial smoke detectors by providing both improved nuisance source immunity with generally equivalent or faster response times. Areas of improvement have been identified. In particular, it is believed that the prototypes can be made to respond faster to long smoldering fires.

McGill R. A. et al. (1993). Who Studied in the Fire Detection by Surface Acoustic Wave Chemical Sensor Systems N Surface Acoustic Wave (SAW) Chemical Sensor systems have been developed to detect and identify fire threats for shipboard materials. The SAW sensor system is an electronic device that employs an array of SAW devices as a "nose" for chemical vapor detection. Each SAW device in an array is coated with a different polymeric material that selectively absorbs different chemical vapors. Chemical vapors released by thermal decomposition of fire fields (e.g. insulation on electrical cable and thermal insulation foam) provide fingerprint patterns from the sensor array that allow identification of the source material associated with a flaming fire, smoldering fire or the threat of a fire (prior to release of smoke). A neural network routine that was trained with over 500 patterns from fire vapor tests correctly identified the source material for all fire threats tested, and hazardous chemical vapors from spills, leaks or chemical agent attack. Sensor responses are reversible, so an area exposed to toxic fumes can be monitored in real times as a decontaminating procedure progresses to a safe condition for personnel to enter the area.

Shaffer Ronald E et al.(2000). Who continue Development of an Early Warning Multi-criteria Fire Detection System: Analysis of Transient Fire Signatures Using a Probabilistic Neural Network (PNN) 1999. Experiments are described to study the effects of various PNN training parameters and to determine the optimal sensor suite combination, which enables both early fire detection and high nuisance source rejection. Comparisons are made between the candidate sensor arrays, commercial fire detection systems, and sensor arrays proposed in previous reports. Recommendations and directions for future research are also given.

Horner April et al. (2000). Who explained in the Aircraft Materials Fire Test Handbook, the purpose of the Aircraft Materials Fire Test Handbook is to describe all FAA-required fire test methods for aircraft materials in a consistent and detailed format.

The appendices contain the following information: FAA fire safety regulations, FAA approval process, aircraft materials, regulatory methodology used by other countries, aircraft industry internal test methods and guidelines, laboratories actively using fire test methods, and commercial manufacturers of fire test equipment.

Ronald E. Shaffer et al. (2000), who explained in the Development of an Early Warning Multi-criteria Fire Detection System: Analysis using a Probabilistic Neural Network. In this work, the analysis of transient fire signatures is studied using a probabilistic neural network (PNN). Experiments are described to study the effects of various PNN training parameters and to determine the optimal sensor suite combination, which enables both early fire detection and high nuisance source rejection. Comparisons are made between the candidate sensor arrays, commercial fire detection systems, and sensor arrays proposed in previous reports. Recommendations and directions for future research are also given.

RESEARCH METHODOLOGY

Conceptual Research Mode

The conceptual model is developed based upon the modification and integration of previous studies in fire emulator / detector evaluator (FE/DE) Figure 1 on page 4, Test Section Side View, The fire sources chosen for this study cover a wide range of fire phenomena. They consist of the following:

(1) A flaming fire indicative of a plastic or liquid hydrocarbon pool fire,

(2) A "low-smoke" flaming fire that consists of ethanol-soaked cotton-polyester blend fabric,

(3) A smoldering cotton wick fire, and

(4) A paralyzing mixed plastics plaque obtained from the FAA Technical Center.

Two nuisance sources chosen to represent potential source of false alarms due to environmental conditions in aircraft cargo compartments were emulated. They consist of the following:

(1) Dust exposure, and

(2) An oil mist aerosol.

This general model is to set the scope and details for data collecting, consideration to make decision benefit cost or the new criteria device for aircraft safety and analyzing.

Analysis Principle

Fire and false alarm events in operation were extracted from different data base and compiled as figure 11 shown below.

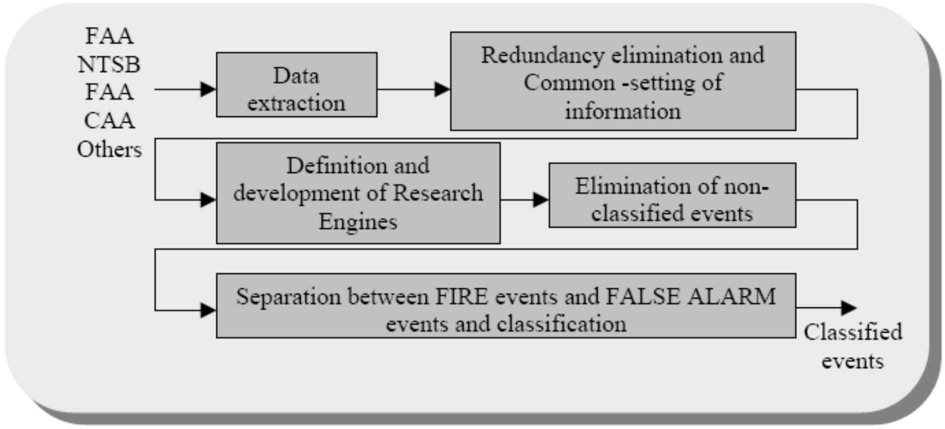


Figure 15 Fire and False Alarm Events Analysis

Source: February 2001 International Conference on Automatic Fire Detection "AUBE '01" 12 th

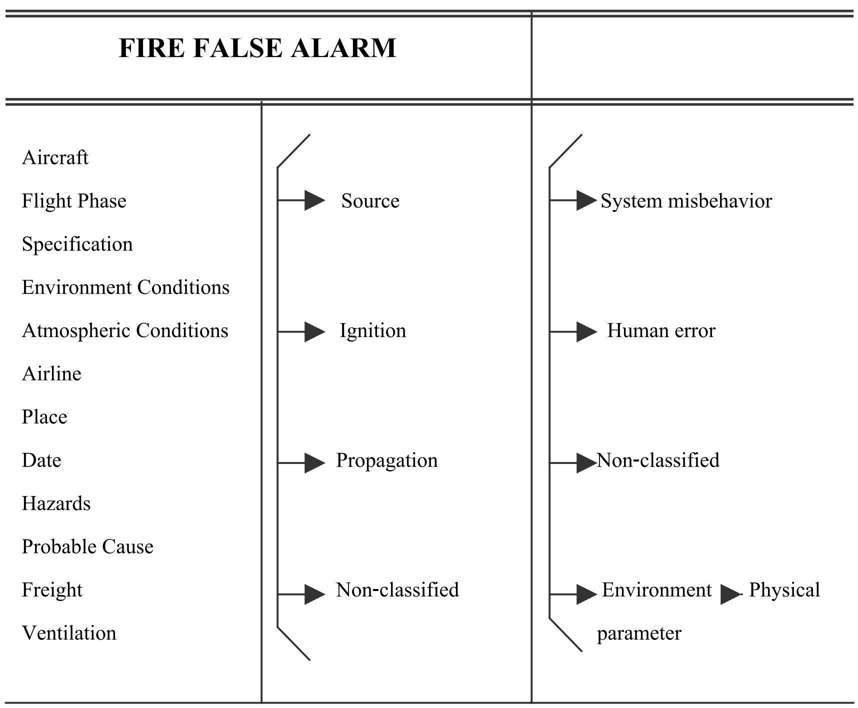


Figure 16 Events Classification Logic

Source: February 2001 International Conference on Automatic Fire Detection "AUBE '01" 12 th

The fire false alarm classification logic was applied: It is to be noted that at the time of the event, most of the here-above information was not recorded (and practically impossible to retrieve after).

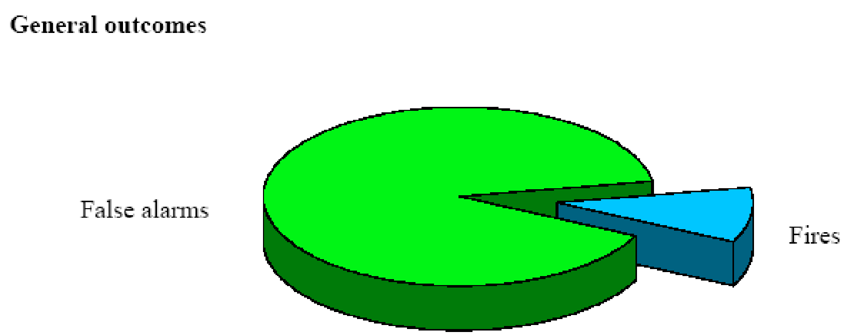


Figure 17 Ratio of Fire/ False Alarm

Source: February 2001 International Conference on Automatic Fire Detection "AUBE '01" 12 th

In this graphic, regional aircraft are very few represented; the overall ratio (90% of false fire warnings) would be higher if this aircraft category was totally included.

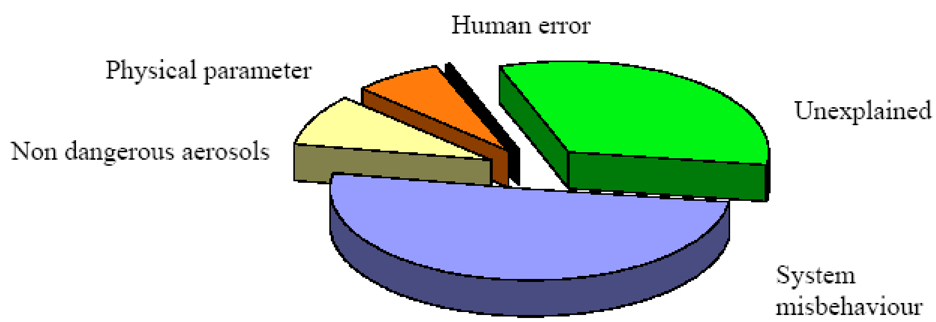


Figure 18 False Alarm Analysis

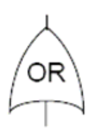
Source: February 2001 International Conference on Automatic Fire Detection "AUBE '01" 12 th

In most of the cases, the conditions in the cargo compartment at the time of the alarm were not exactly known by the pilots or the crew, therefore false alarm events were often considered unexplainable or attributed to a system malfunction whereas a better knowledge of these conditions would have led to a different classification.

However, system misbehavior under degraded situations (wiring failures, power supply failures, management of redundancies in case of internal failures,) take probably a significant part in the overall ratio and have to be considered as an improvement axis.

Principle of Theory and Process of Research Methodology

The need to create or review multiple projects at the same time has been made effortless with Tool-Kit. Tool-Kit will allow you to create or open multiple projects simultaneously. Projects can consist of many different Fault Tree systems that can also be analyzed simultaneously. Merge all or a portion of each system together to create a master Fault Tree. This powerful option will enable you to manage many different projects and systems, create a new system by reusing all or a portion of an existing system that has been analyzed plus copy/paste gates and events between projects and /or systems, Fault Tree systems (Logic diagram) below.



= component which is containing the failure or failure / year

Q-value = 0.000000125 or

= μ of value failure

$R_A(t) = e^{-\mu} = e^{-Q}$

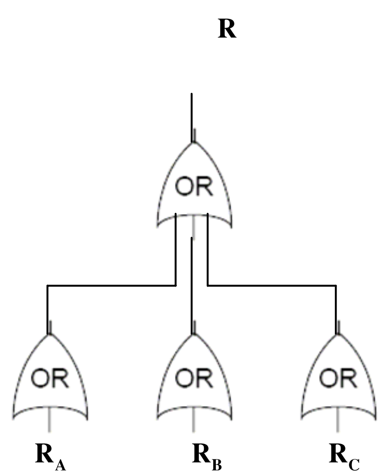


Figure 19 Fault Tree Systems (Logic diagram)

Source: Clemens (2002)

Therefore the probability of the tipple tree connection is

$$R = (R_A)(R_B)(R_C)$$

1. **Fault Tree Analysis technique**

The Fault Tree is a graphic "model" of the pathways with in a system that can lead to a foreseeable, undesirable loss event. The pathways interconnect contributory events and conditions, using standard logic symbols. Numerical probabilities of occurrence can be entered and propagated through the model to evaluate probability of the foreseeable, undesirable event. There is only one of many system safety analytical tools and techniques should be considered.

Fault Tree Analysis is best applied to cases with large, perceived threats of loss, i.e., high risk. Numerous potential contributors to a misshape. Complex or multi-element systems/ processes. Already - identified undesirable events.

Fault Tree Analysis is one of the many modules within the Item Tool-Kit application. Item Software's Fault Tree module can provide useful failure probability and system reliability data concerning the likelihood of a failure and the means by which such a failure could occur.

With the detailed output of each Fault Tree Analysis, efforts to improve system safety and reliability can be highly focused and tailored to your system by using the quantifying results from the data you input. Additionally, a Fault Tree Analysis can help prevent a failure from occurring beforehand by the analysis of the system data you input.

2. **Using the Fault Tree Module**

The Fault Tree Analysis application uses a Fault Tree workspace area where all project, system, and Fault Tree data and graphics are entered. This area is the foundation on which you build your projects. The workspace area consists of menus, toolbars, and project and system windows.

Fault Trees are one of the most widely used methods in system reliability and failure probability analysis. A Fault Tree is a graphical representation of events in a hierarchical, tree-like structure. It is used to determine various combinations of hardware, software, and human error failures that could result in a specified risk or system failure. System failures are often referred to as top events. A deductive analysis using a Fault Tree begins with a general conclusion or hazard, which is displayed at the top of a hierarchical tree. This deductive analysis is the final event in a sequence of events for which the Fault Tree is used to determine if a failure will occur or, alternatively, can be used to stop the failure from occurring. The remainder of the Fault Tree represents parallel and sequential events that potentially could cause the conclusion or hazard to occur and the probability of this conclusion. This is often described as a ″top down″ approach.

Fault Trees are composed of events and logical event connectors (OR-gates, AND-gates, etc.). Each event node's sub-events (or children) are the necessary pre-conditions that could cause this event to occur. These conditions can be combined in any number of ways using logical gates. Events in a Fault Tree are continually expanded until sub-events are created for which you can assign a probability. Events in a Fault Tree describe the different levels of system abstraction. Higher nodes represent a high level of abstraction while lower nodes represent a low level of abstraction.

The main purpose of Fault Tree Analysis is to evaluate the probability of the top event using state-of-the-art analytical and/or statistical methods. These calculations involve system quantitative reliability and maintainability data, such as failure probability, failure rate, expected failure, down time, repair rate, etc

3. <u>Fault Tree Construction</u>

Tool-Kit offers flexible, powerful and easy ways for constructing Fault Trees. You can simply add different gates and events in the System Window to create a hierarchy of your system; Tool-Kit will construct the Fault Tree Diagram for you. Or, you can build your Fault Tree the traditional way by adding gates and events in the Diagram Window.

4. Multiple Projects and Systems

The need to create or review multiple projects at the same time has been made effortless with Tool-Kit. Tool-Kit will allow you to create or open multiple projects simultaneously. Projects can consist of many different Fault Tree systems that can also be analyzed simultaneously. Merge all or a portion of each system together to create a master Fault Tree. This powerful option will enable you to manage many different projects and systems, create a new system by reusing all or a portion of an existing system that has been analyzed plus copy/paste gates and events between projects and /or systems

ANALYSIS AND DISCUSSION

Analysis

1. Fault Tree Analysis Produces

Graphic display of chains of events/conditions leading to the loss event. Identification of those potential contributors to failure that are ″critical.” Improved understanding of system characteristics. Qualitative/quantitative insight into probability of the loss event selected for analysis. Identification of resources committed to preventing failure. Guidance for redeploying resources to optimize control of risk. Documentation of analytical results.

1.1 Some Definitions

FAULT •An abnormal undesirable state of a system or a system element* induced 1) by presence of an improper command or absence of a proper one, or 2) by a failure (see below). All failures cause faults; not all faults are caused by failures. A system, which has been shut down by safety features, has not faulted.

FAILURE •Loss, by a system or system element*, of functional integrity to perform as intended, e.g., relay contacts corrode and will not pass rated current closed, or the relay coil has burned out and will not close the contacts when commanded -the relay has failed; a pressure vessel bursts -the vessel fails. A protective device, which functions as intended has not failed, e.g., a blown fuse.

1.2 The Logic

TOP Event - Foreseeable, undesirable event, toward which all fault tree logic paths flow, or Intermediate event-describing a system state produced by antecedent events.

″Or″ Gate - Produces output if any input exists. Any input, individual, must be necessary and sufficient to cause the output event.

″**And**″ **Gate** - Produces output if all inputs co-exist. All inputs, individually must be necessary and sufficient to cause the output event Most

Basic Event-Initiating fault/failure not developed further. (Called ″Leaf,″ ″Initiator,″ or ″Basic.″) The Basic Event marks the limit of resolution of the analysis.

Fault Tree Analysis is Best Applied to Cases with

- Large, perceived threats of loss, i.e., high risk
- Numerous potential contributors to a mishap
- Complex or multi-element systems/processes
- Already-identified undesirable events
- Indiscernible mishap causes.

Fault Tree Analysis Produces

- Graphic display of chains of events/conditions leading to the loss event
- Identification of those potential contributors to failure, “critical ”
- Improved understanding of system characteristics
- Qualitative/quantitative insight into probability of the loss event selected for analysis
- Identification of resources committed to preventing failure
- Guidance for redeploying resources to optimize control of risk
- Documentation of analytical results

Primary (or Basic) Failure

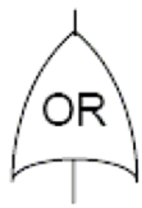
- The failed element has seen no exposure to environmental or service stresses exceeding its ratings to perform. E.g., fatigue failure of a relay spring within its rated lifetime; leakage of a valve seal within its pressure rating.

Secondary Failure

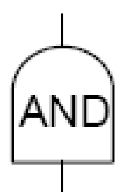
- Failure induced by exposure of the failed element to environmental and/or service stresses exceeding its intended ratings. E.g., the failed element has been improperly designed, or selected, or installed, or calibrated for the application; the failed element is overstressed/under qualified for its burden.

2. <u>**The Logic Symbols**</u>

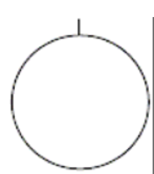
TOP Event – foreseeable, undesirable event, toward which all fault tree logic paths flow, or Intermediate event–describing a system state produced by antecedent events.



“ **OR** ” **Gate** – produces output if any input exists. Any input, individual, must be (1) necessary and (2) sufficient to cause the output event.



“ **AND** ” **Gate** – produces output if all inputs co-exist. All inputs individually must be (1) necessary and (2) sufficient to cause the output event Most Fault Tree Analyses can be carried out using only these four symbols.



Basic Event – Initiating fault/failure, not developed further.

Basic Event (Called “Leaf,” “Initiator,” or “Basic.”) The Basic Event marks the limit of resolution of the analysis. Events and Gates are not component parts of the system being analyzed. They are symbols representing the logic of the analysis. They are bi-modal. They function flawlessly.

3. **Steps in Fault Tree Analysis**

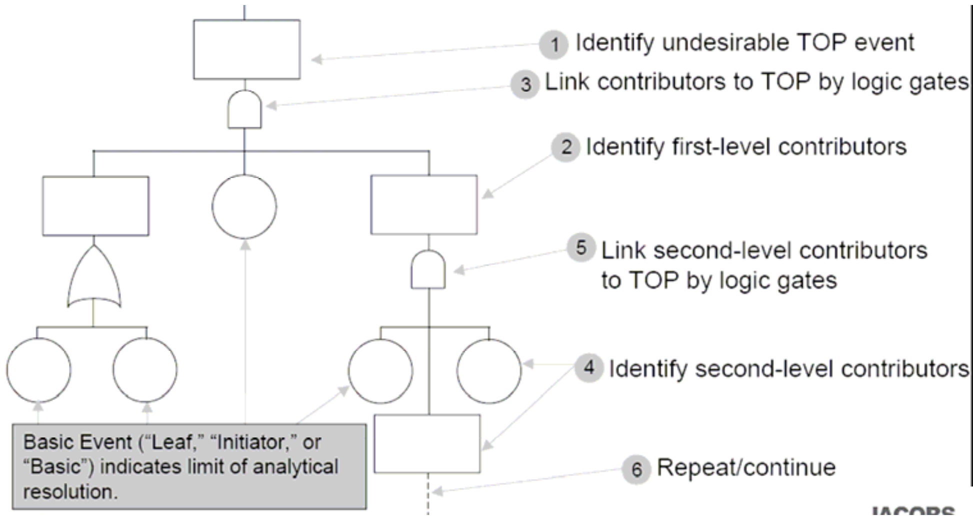


Figure 20 Steps in Fault Tree Analysis

Source: Clemens (2002)

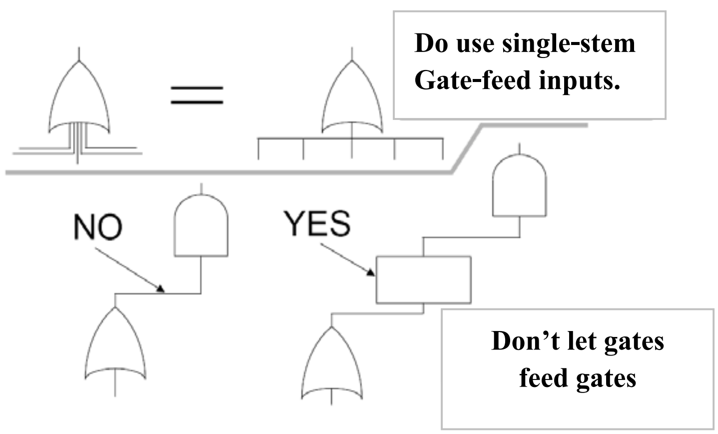


Figure 21 More Rules and Conventions

Source: Clemens (2002)

- S = Successes
- F = Failures
- Reliability… $R = \frac{S}{(S+F)}$
- Failure Probability… $P_F = \frac{F}{(S+F)}$

$$R + P_F = \frac{S}{(S+F)} + \frac{F}{(S+F)} \blacksquare 1$$

$$\lambda = \textbf{Fault Rate} = \frac{1}{\textbf{MTBF}}$$

(Fault rates are constant, λ = 1/MTBF = K)

Figure 22 Reliability and Failure Probability Relationships
Source: Clemens (2002)

Most system elements have fault rates (λ = 1/MTBF) that are constant (λ = 0) over long periods of useful life. During these periods, faults occur at random times.

The future is independent of the past i.e., future states available to the system depend only upon its present state and pathways now available to it, not upon how it got where it is.

3.1 Fault Tree Module Providers a Method to

- Compute unreliability and unavailability
- Analyze Uncertainty and Sensitivity
- Analyze Common Cause Failure (CCF)
- Produce Minimal Cut Sets
- Fault Tree Sequencing, Initiator and Enabler, Initiator Only, Enabler Only
- Define event failure models
- Determine the importance of elements in a system

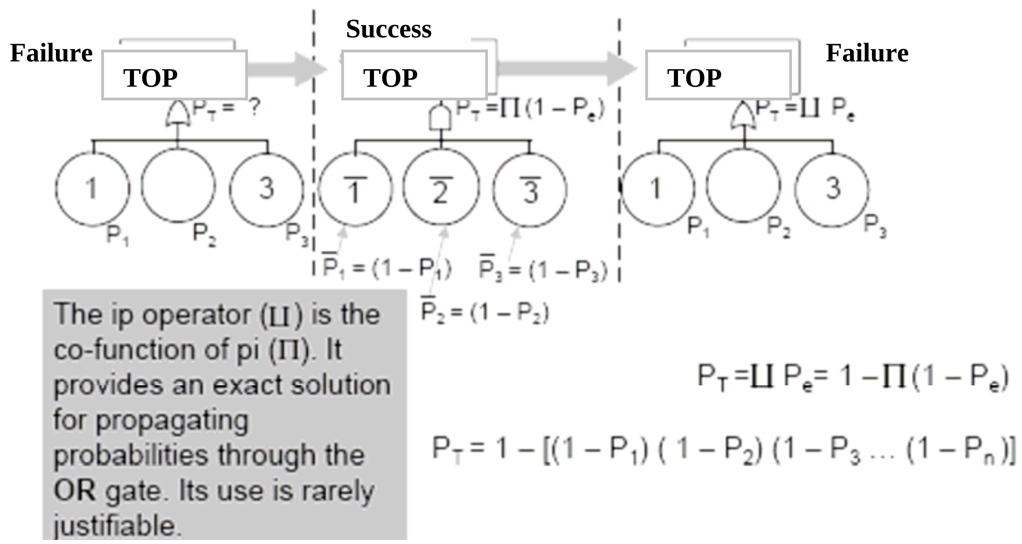


Figure 23 An Exact Solution (OR-Gate)
Source: Clemens (2002)

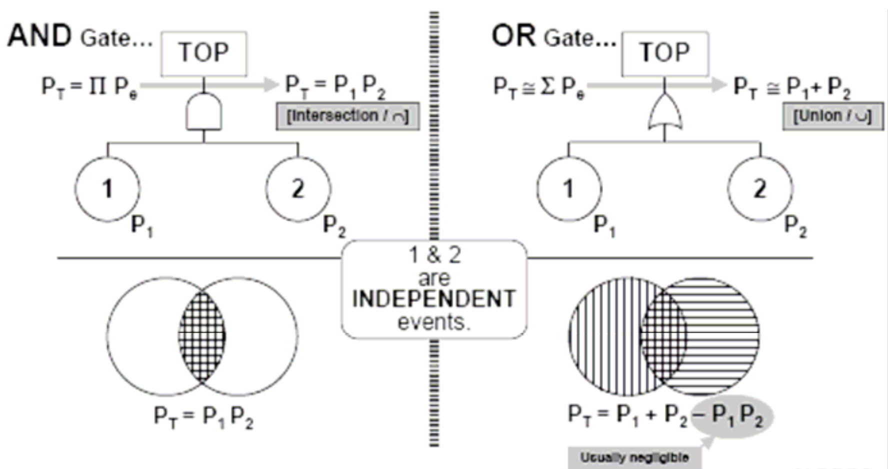


Figure 24 PF Propagation Through Gates
Source: Clemens (2002)

4. Using the Fault Tree Module

The Fault Tree Analysis application uses a Fault Tree workspace area where all project, system, and Fault Tree data and graphics are entered. This area is the foundation on which you build your projects. The workspace area consists of menus, toolbars, and project and system windows.

The Fault Tree workspace area features a Multiple Document Interface (MDI), which allows you to:

- Choose which windows to display, and move and resize all open windows.
- Open and create multiple Fault Tree projects at the same time in order to compare analysis results.
- Drag and drop gate and event components between projects. This feature allows you to quickly create a new project by reusing components from other projects.

Fault Trees are one of the most widely used methods in system reliability and failure probability analysis. A Fault Tree is a graphical representation of events in a hierarchical, tree-like structure. It is used to determine various combinations of hardware, software, and human error failures that could result in a specified risk or system failure. System failures are often referred to as top events. A deductive analysis using a Fault Tree begins with a general conclusion or hazard, which is displayed at the top of a hierarchical tree. This deductive analysis is the final event in a sequence of events for which the Fault Tree is used to determine if a failure will occur or, alternatively, can be used to stop the failure from occurring. The remainder of the Fault Tree represents parallel and sequential events that potentially could cause the conclusion or hazard to occur and the probability of this conclusion. This is often described as a "top down" approach.

Fault Trees are composed of events and logical event connectors (OR-gates, AND-gates, etc.). Each event node's sub-events (or children) are the necessary pre-conditions that could cause this event to occur. These conditions can be combined in any number of ways using logical gates. Events in a Fault Tree are continually expanded until sub-events are created for which you can assign a probability. Events in a Fault Tree describe the different levels of system abstraction. Higher nodes represent a high level of abstraction while lower nodes represent a low level of abstraction.

The main purpose of Fault Tree Analysis is to evaluate the probability of the top event using state-of-the-art analytical and/or statistical methods. These calculations involve system quantitative reliability and maintainability data, such as failure probability, failure rate, expected failure, down time, repair rate, etc

Fault Tree Analysis is a well-established methodology that relies on solid theories such as Boolean logic and Probability Theory. Boolean logic is used to reduce the Fault Tree structure into the combinations of events leading to failure of the system, generally referred to as Minimal Cut Sets, many of which are typically found. Probability Theory is then used to determine probabilities that the system will fail during a particular mission, or is unavailable at a particular point in time, given the probability of the individual events. Additionally, probabilities are computed for individual Minimal Cut Sets, forming the basis for their ranking by importance with respect to their reliability and safety impact.

Using this detailed information, efforts to improve system safety and reliability can be highly focused, and tailored to your individual system. Possible design changes and other risk-mitigating actions can be evaluated for their impact on safety and reliability, allowing for a better-informed decision making process and improved system reliability. This type of analysis is especially useful when analyzing large and complex systems where manual methods of fault isolation and analysis are not viable.

Fault Trees are used during Reliability and Safety assessments to graphically represent the logical interaction and probabilities of occurrence of component failures and other events in a system. The interactions are captured using a tree structure of Boolean operators gates, which decomposes system level failures to combinations of lower-level events. The analysis of such Fault Trees, identifies and ranks combinations of events leading to system failure, and provides estimates of the system's failure probability.

Failure induced by exposure of the failed element to environmental and/or service stresses exceeding its intended ratings. E.g., the failed element has been improperly designed, or selected, or installed, or calibrated for the application; the failed element is overstressed/under qualified for its burden.

Discussion

1. Software Reliability Improvement Techniques

Good engineering methods can largely improve software reliability. Before the deployment of software products, testing, verification and validation are necessary steps. Software testing is heavily used to trigger, locate and remove software defects. Software testing is still in its infant stage; testing is crafted to suit specific needs in various software development projects in an ad-hoc manner. Various analysis tools such as trend analysis, fault-tree analysis, Orthogonal Defect classification and formal methods, etc, (Figure 21) can also be used to minimize the possibility of defect occurrence after release and therefore improve software reliability.

After deployment of the software product, field data can be gathered and analyzed to study the behavior of software defects. Fault tolerance or fault/failure forecasting techniques will be helpful techniques and guide rules to minimize fault occurrence or impact of the fault on the system.

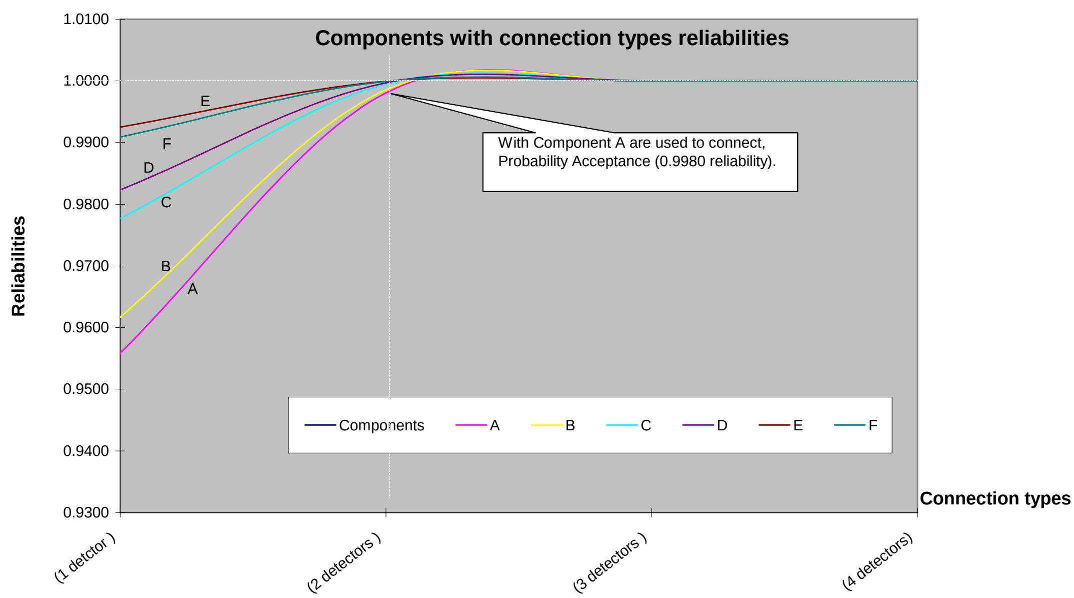


Figure 25 Reliability of each Component Types Connection

Source: Exel program computing

Table 1 Component Part Number Autronics 2156-556 (A-General component)

General Component part number Autronics 2156-556 (A)		
Number of component used	**Cost Added US$**	**Rs / Achieved**
	999.6	0.9559
	1999.2	0.99805519
	2998.8	0.999914234
	3998.4	0.999996218

Source: MS-Exel program computing

Table 2 Difference Costs of (A-General component) with diff. Connection

Type-Connection & Cost expense	**Costs US $**
General Existing	8996.4
Double	17992.8
Tipple	26989.2
Two Pairs	35985.6

Source: MS-Exel program computing

Table3 Detector Cost of Investment (cost of maintenance)

Detector/Type A	**Costs**	**Reliability**
Detector 1 ea	999.60 US$	Reliability = 0.955889
Detector 9 ea	8,996.4 US$	Reliability = 0.955889
Detector 18 ea	17,992.8 US$	Reliability = 0.99977
Detector 27 ea	26,989.2 US$	Reliability = 0.999998875

Source: MS-Exel program computing

Table 4 Detector Reliability & False Detect

	General Comp. Type A	Autronics/B 2156-646	Autronics/C 2156-556	Autronics/D 2156-34A	Autronics/E 2156-37	Autronics/F 2156-46A
Comp.Relia.&	0.9559	0.9617	0.9777	0.9723	0.9725	0.9909
False Detect	0.0005	0.0003	0.0002	0.0005	0.0008	0.0006

Source: Autronics Corporation Irwindale California, MS-Exel program computing

Table 5 Part Specification Data

DATA 1.	General Type A	2156-646 Type B	2156-556 Autronics/C	2156-34A Autronics/D	2156-37 Autronics/E	2156-646 A Autronics/F
Reliability	0.9559	0.9617	0.9777	0.9823	0.9925	0.9909
Q′ (False -Alarm)	0.0005	0.0003	0.0002	0.0005	0.0008	0.0006

Source: Autronics Corporation Irwindale California, MS-Exel program computing

Table 6 Types of Components Data & Description

Type of Components	Unit unreliability	Component reliability	Unit costs/US$
A = General Component	0.0441	0.9559	999.6
B = Autronics 2156-646	0.0383	0.9617	1116.5
C = Autronics 2156-556	0.0223	0.9777	2404
D = Autronics2156-34A	0.0177	0.9823	2784
E = Autronics 2156-37	0.0075	0.9925	2927.9
F = Autronics 2156-646A	0.0091	0.9909	2558

Source: Autronics Corporation Irwindale California

Table 7 Smoke Detectors Types & Costs

Smoke Detectors Types & Costs				
DATA 2.				
	P/n	474942 for MD11	value is	**999.6** US. $/ A
	P/n	486061 for B743	value is	1116.5 US. $/ B
	P/n	935701 for A330	value is	2404.0 US. $/ C
	P/n	943251 for B744	value is	2784.0 US. $/ D
	P/n	470565 for A360	value is	2927.9 US. $/ E
	P/n	2156-646A –	value is	2558.0 US. $/ F

Source: Autronics Corporation Irwindale California, Component Maintenance Manual Chapter 26-16-16, Oct 13/04

Table 8 Components; Types & System Reliability (Rs)

System Reliability (Rs) Achieved with different types & number of component used						
Connection types;	1	2-parallel	3-tipple	4-two pair	5	6
Component Types/ Reliability						
A	0.9559	0.99805519	0.999914234	0.999996218	-	-
B	0.9617	0.99853311	0.999943818	0.999997848	-	-
C	0.9777	0.99950271	0.99998891	0.999999753	-	-
D	0.9823	0.99968671	0.999994455	0.999999902	-	-
E	0.9925	0.99994375	0.999999578	0.999999997	-	-
F	0.9909	0.99991719	0.999999246	0.999999993	-	-

Source: Autronics Corporation Irwindale California, MS-Exel program computing

Component reliabilities which were complied by MS-Exel program (figure 22) and with more details flexible display by Dephi programming complied to display each of component types number of combination, cost of components investment curve & display (sort code in appendix).

Delphi program, figure 23,24 and 25 on the next pages to optimized the reliabilities and total cost investment to make decision. This has been an introduction to the topic of the efficiency analysis of both interactive and recursive algorithms. The technique used to analyze those algorithms is not to time them with a clock and see how fast they run.

This approach is too greatly influenced by the characteristics of the data set selected and the machine on which it is run. Instead, we characterize the asymptotic or limiting behavior of an algorithm so the problem size group very large. This allow us to determine the complexity, or order of the algorithm. Then we can choose the lowest order algorithm we can find. This guarantees that, to within a constant factor, we will achieve the highest possible level of efficiency. More sort code display on the appendix pages.

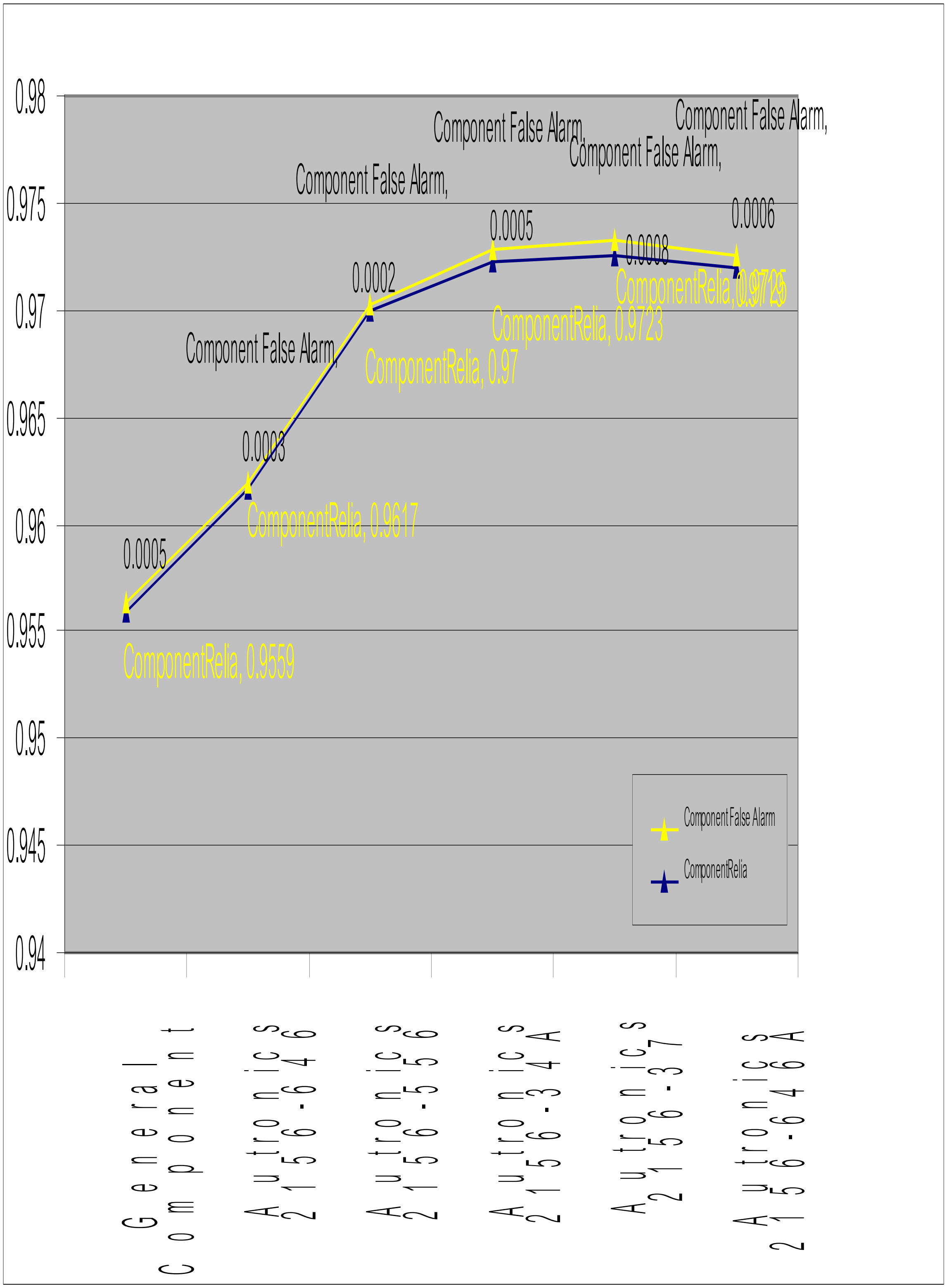


Figure 26 Compare Component Reliabilities

Source: Component reliabilities complied by MS-Exel program

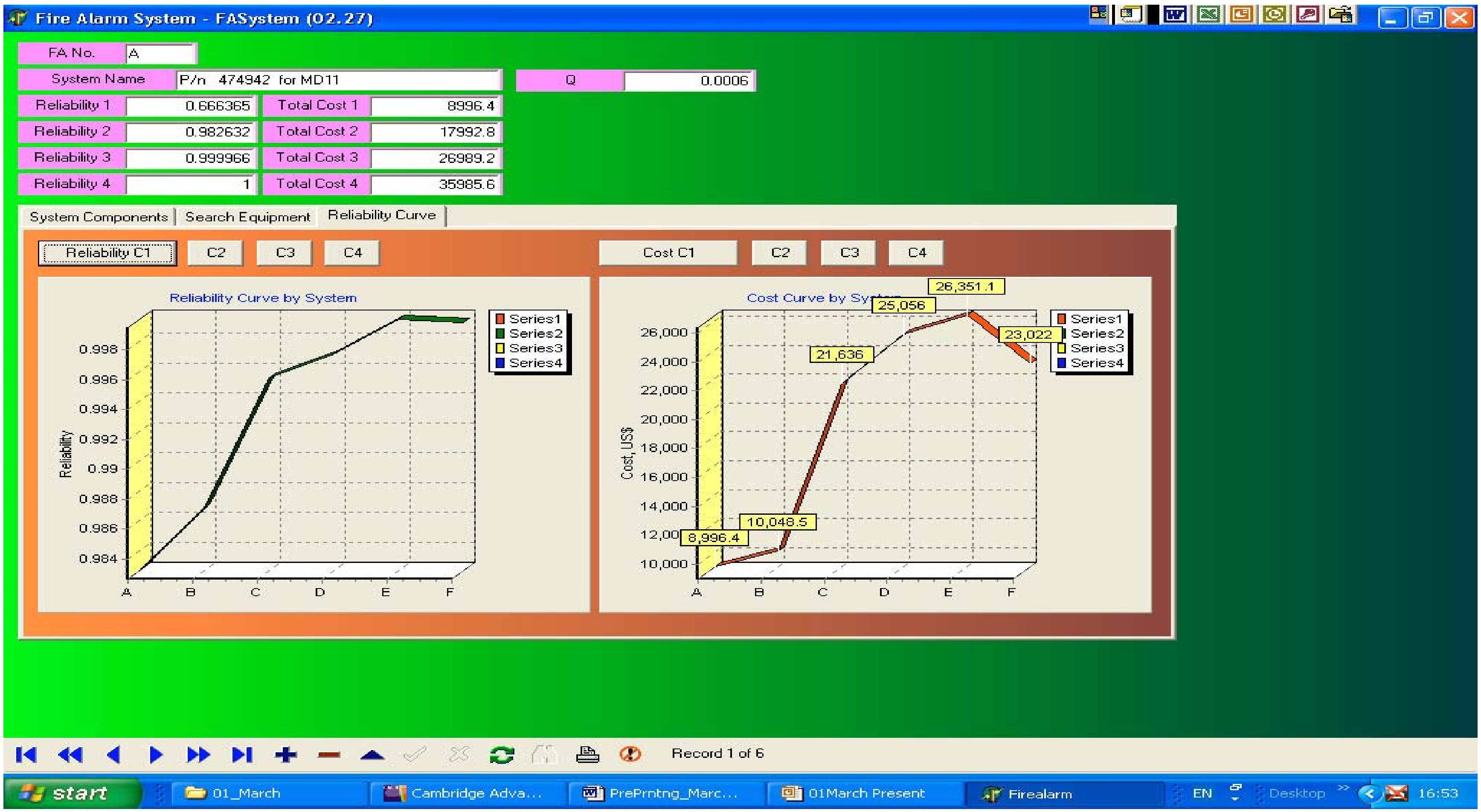


Figure 27 Component A Computed by Delphi Program to Optimized the Reliabilities and Total Cost Investment to Make Decision

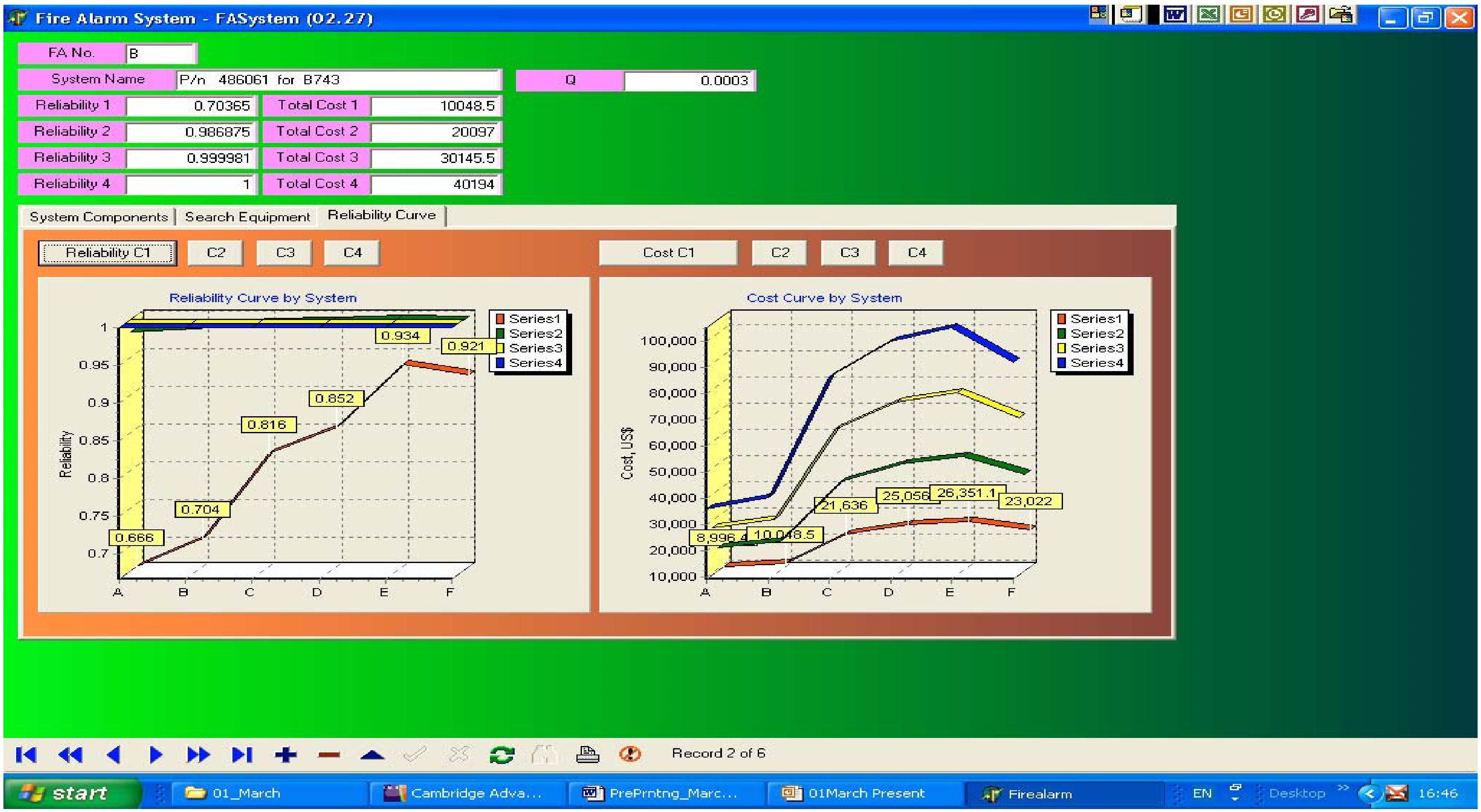


Figure 28 Component B Computed by Delphi Program to Optimized the Reliabilities and Total Cost Investment to make Decision.

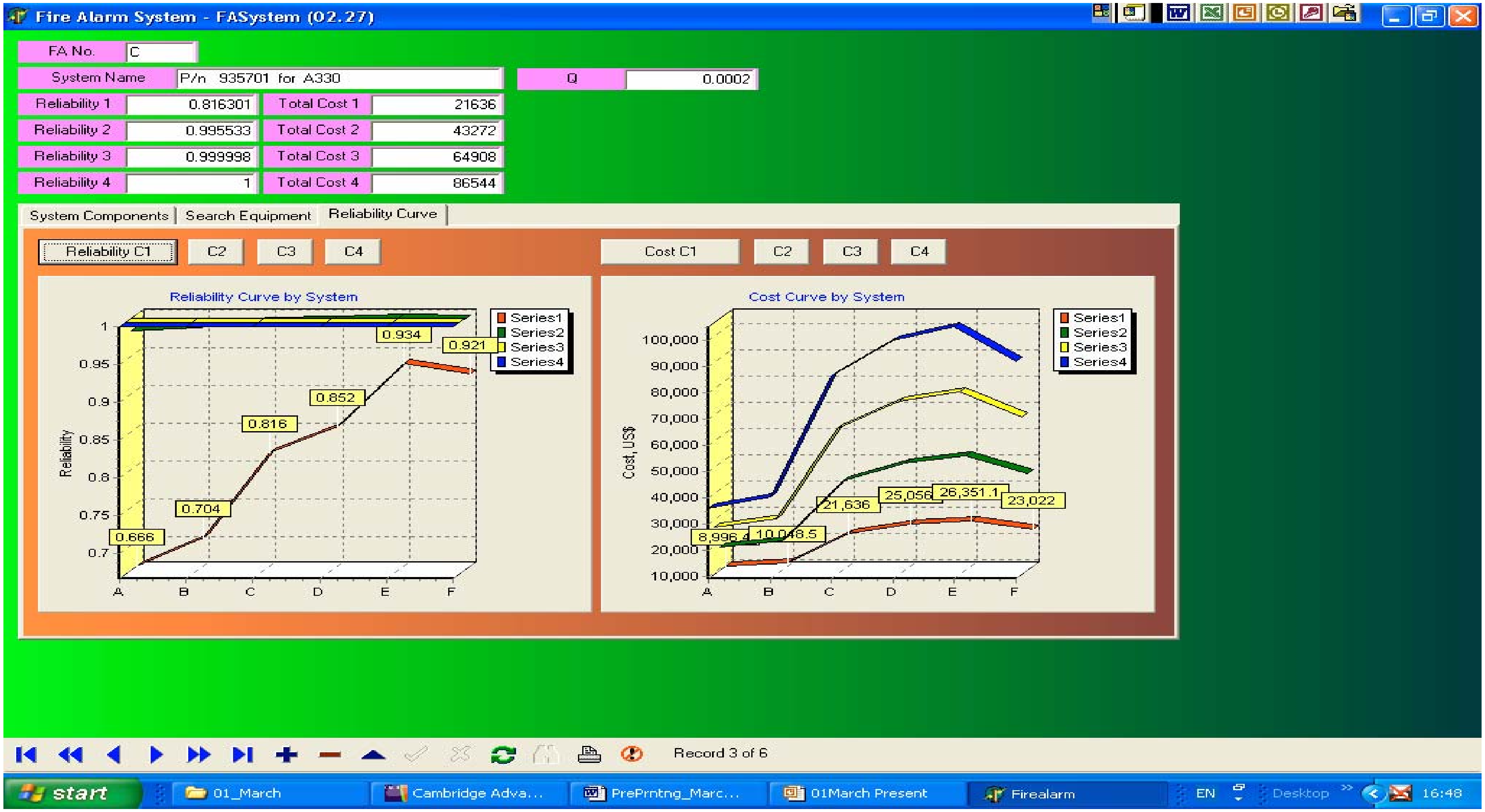


Figure 29 Component C Computed by Delphi Program to Optimized the Reliabilities and Total cost Investment to Make Decision.

MATERIALS AND METHODS

Materials

- Detector interface for visual display of sensor status on a PC: 769805
- Detector bases for the most varied of requirements
    - Standard version: 781490
    - With relay output: 781491
    - With open collector output: 781492
    - With isolator: 781493
- Detector lock: 781496
- Protective detector cage against unauthorized removal: 781550
- Ionization smoke detector Part No. 761071
- Fixed heat detector Part No. 761171
- Rate-of-rise heat detector Part No. 761271
- Optical smoke detector Part No. 761371
- OT multi-sensor detector Part No. 761373
- OTI multi-sensor analog detector Part No. 761973
- Electrical Power Supply (Ground Cart) with 110 Volts/400 Hz
- Multi-meter Rang 500 VAC Max.
- A set of PC CPU 1 GHz, Ram 256 MB with window XP, printer & scanner.
- The DELPHI program version 7.1 for window.
- 70 gram White Paper
- SD Scandisk cap.64Mb, 128Mb, 256Mb, and Thumb Drive

Methods

Suppression Characteristic Suppression system for commercial airliners International Aero Technologies and Fire Pass have developed a novel method of protecting airliner cargo compartments. Low Pressure dual fluid water mist is proving to be an answer to HALON Replacement in commercial aircraft cargo compartments. When combined with Hypoxic air the patented low-pressure dual fluid nozzle is far surpassing any HALON alternative material tested to date. In the links below the temperature and test data as shown. Minimum Performance Standard for Aircraft Cargo Compartment HALON (Replacement Fire Suppression Systems final rule was issued this summer 2004).

Federal Aviation Regulations (FARS) and Joint Airworthiness Requirements (JARS) require fire suppression systems for some classifications of cargo compartments. In the past, the aircraft industry selected HALON 1301 total flood fire suppression systems as the most effective means for complying with the regulations. Because of the ban on production of HALON 1301 (effective January 1994, as mandated by the Montreal Protocol), new fire suppression systems will need to be certified when HALON 1301 is no longer available. The tests described in this standard are one part of the total Federal Aviation Administration (FAA) and the Joint Aviation Authority (JAA) certification process for cargo.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Fire and nuisance alarm scenarios for aircraft cargo compartments were reproduced in the FE/DE. The data gathered contains particulate; combustion gas and temperature raise values that may be used to identify sensor combinations to discriminate between fire and non-fire conditions. Background levels of particulate, combustion gas and temperature fluctuations need to be included in any analysis leading to sensor selection and alarm algorithm design.

Most of the cargo compartments on passenger carrying aircraft are required to have fire detection systems that provide a visible and aural alarm in the cockpit. Current Regulations require that the detectors alarm within one minute of the start of a fire and at a fire size that produces temperatures significantly below those that will substantially decrease the structural integrity of the airplane. Flight tests are required to demonstrate compliance with these regulations. The fire detectors in use today are predominately photoelectric or ionization smoke detectors. While these detectors are effective at detecting actual fires they are also prone to alarm from airborne particles not associated with fires. The use of multiple sensors and appropriate alarm algorithms have the potential to better discriminate between actual fires and nuisance alarm sources.

When airplanes flight manuals, they are containing the approved procedures to follow for a variety of situations. In the case of a cargo compartment fire detector alarm, the typical flight manual procedure is to shut off any applicable ventilation, discharge fire suppression agent if equipped, and divert and land at the nearest suitable airport (according to an emergency checklist procedures). What constitutes the nearest suitable airport is at the discretion of the flight crew. In the discussion section of the final rule for Class D cargo compartments mentioned previously, there is some discussion regarding the cost of diversions.

These conditions, if not corrected, could result in possible confusion as the flight crew performs their duties in response to a smoke/fumes emergency, which could subsequently impair their ability to correctly identify the source of the smoke/fumes and subsequently affect the continued safe flight and landing of the airplane.

If not corrected, could result in smoke and possible to reduce the risk of the spread of fire in the aboard aircraft, 'The FAA's track record shows that we don't hesitate to have airlines retrofit the fleet when there is a threat to passenger safety', the new test standard was developed by the FAA with input from world-renowned fire experts. Acceptable level of safety and is proposing an even higher standard for testing and must be performed safely to avoid unintended consequences. This allows for a safe and deliberative process designed to minimize the possibility of creating unintended safety problems, fell short of an acceptable safety level and far below the new standard. It ignites much more easily than other materials and can spread fire because its properties are much different. The other materials performed better than originally anticipated and meet the acceptable level of safety.

1. Cargo-Compartment Smoke Detection & Fire Suppression

Concern over the potential for catastrophic in-flight fires in commercial airplane cargo compartments has focused attention on cargo compartments that depend on oxygen deprivation to prevent and suppress combustion (Class D compartments). Though the risk of fire in a cargo compartment is statistically very low, the U.S. Federal Aviation Administration (FAA) has issued a rule change to require airplanes registered in the United States to convert all Class D cargo compartments to Class C or Class E compartments by installing a smoke-detection system (Class E), fire-suppression system, or both (Class C), depending on whether the airplane is a passenger or freighter configuration.

For many years, commercial airplanes have relied on oxygen deprivation to control the risk of cargo-compartment fires below the main passenger cabin. However, a cargo fire in a commercial airplane that resulted in hull loss has caused the perception of cargo-fire risk to grow. In response, the U.S. Federal Aviation Administration (FAA) issued a rule change on March 18, 1998, that mandates the conversion of Class D compartments to Class C or Class E compartments by installing smoke-detection systems, fire-suppression systems, or both.

Historical and recent use of Class D compartments.

Current criteria for Class C compartments.

Current criteria for Class E compartments.

Technical assistance available to operators.

Tested and validated design.

Source: Boeing commercial airplane, 2001

2. The Benefit –cost analysis model

Benefit-cost analysis is simply rational decision-making. People use it every day, and it is older than written history. Our this modification project about EFWD model of costs and benefits is sometimes inadequate, however, when the alternatives are complex or the data uncertain. Then we need formal techniques to keep our thinking clear, systematic and rational. These techniques constitute a **model** for doing benefit-cost analysis. They include a variety of methods:

- identifying alternatives;
- defining alternatives in a way that allows fair comparison;
- adjusting for occurrence of costs and benefits at different times;
- calculating dollar values for things that are not usually expressed in Thai Baht;
- coping with uncertainty in the data, to save own components; and
- summing up a complex pattern of costs and benefits to guide decision-making.

It is important to keep in mind that techniques are only tools. They are not the essence. The essence is the clarity of the analyst's understanding of the options.

Method that prevent fire on commercial aircraft, help airlines save money, improve safety, ensure compliance and greatly reduce on-ground delays.

Many of the world's major airline carriers, have been recognized by airline executives, engineers, pilots, maintenance crews and industry analysts for their superior technology, ease of installation, and rapid return on investment.

Solutions use state-of-the-art technologies to remove the ever-present threat of fire on commercial aircraft improve airline safety, ensure compliance with FAA regulations and greatly reduce delays, thereby enabling airlines to focus on faster turns and use their aircraft more efficiently. On the ground and in the air, commercial aircraft more cost-effective to operate and safer to fly.

One of the commentators to the rule estimated the costs associated with diverting to an alternate airport at $30,000 for a narrow-body airplane and $50,000 for a wide-body airplane and the Federal Aviation Administration (FAA) agreed that those estimates were probably in the correct range. In addition to the direct costs associated with a diversion, there could also be an increased safety risk due to a variety of factors such as unfamiliar airports, less effective navigational aids, inadequate maintenance facilities, shorter runways, inferior Airport Rescue and Fire Fighting (ARFF) capabilities, etc. Obviously, diversions due to false cargo compartment fire alarms are undesirable. The above reasons, a high ratio of false alarms to actual fire or smoke events can erode confidence in the detection system and possibly delay appropriate action in the event of a real smoke or fire emergency.

The purpose of the project is to define the fires that should be detected and the production of smoke, heat and gases from these fires. The tests will be conducted in various sized cargo compartments to measure the accumulation of smoke, heat and gas species over time. The results of the testing will be used to determine effective alarm algorithms for multi sensor detectors and to specify the generation rates of the products of combustion from the fires for certification tests. Certification guidelines for using these types of fire detectors on aircraft do not currently exist. The FAA Technical Center testing is part of a multiple agency effort on this subject involving NASA Glenn Research Center, Sandia National Laboratories, NIST and FAA.

Sources; (David Blake, FAA Technical Center, Fire Safety Section)
http://www.fire.tc.faa.gov/pdf/systems/MultiCriteria%20Fire%20Detector Oct 2004

Recommendations

Thai aircraft fleets responsibility have to consider to make decision for the smoke-detection retrofit design for the old model airplanes is a dual-loop photoelectric system (Appendix Figure B12) that has been demonstrated to detect smoke from any location in the forward or aft cargo compartment within the specified 60-sec limit. All of the following recommended detectors types are used and one of the other things is to consider Optical Smoke Detectors by safety factor designed additional more than a pair of smoke detector position connection with FTA calculated.

Development of safety and cost investment are comprehensive plan to meet a new FAA rule to convert Class D cargo compartments to Class C or Class E compartments. To install smoke-detection systems, fire-suppression systems, or both in existing Class D compartments. Those steps include the certification efforts, system design, service bulletin validations, and kit development to make Class D compartments compliant with Class C or Class E specifications.

The dual-loop system reduces the incidence of false reports by requiring that at least one sensor in each loop detect smoke simultaneously before the annunciator on the flight deck is activated. If power loss prevents either loop from functioning, the system will automatically reconfigure to transmit a warning upon detection of smoke by the sole remaining detection loop. Failure of a single detector in either loop will leave the remaining detectors in the loop functional and capable of detecting smoke anywhere in either cargo compartment within the 60-sec limit.

1. Extinguisher test lights.

A bottle in the air-conditioning mix bay between the forward and aft cargo compartments contains Halon 1301. The Halon bottle can discharge to either compartment, but once activated, the system cannot be reversed to the other compartment. A sensor detects Halon bottle pressure and activates the Halon low-pressure indicator on the flight deck when the bottle discharges or loses pressure.

The TEST switch checks the condition of the discharge nozzles in both compartments. The FWD and AFT indicators illuminate green when the system is functioning normally. Airplanes may not be dispatched with a loaded cargo compartment if the fire-suppression system exhibits any faults.

2. **Detector fault indicator.**

A faulty detector will cause the amber DETECTOR FAULT indicator to illuminate and the FWD or AFT indicator to fail to light, depending on which compartment contains the faulty detector. The flight crew can determine whether the A or B loop contains the fault by selecting position A or B on the detector select switch. When the properly functioning loop is selected, the DETECTOR FAULT indicator will not light, and the FWD and AFT indicators will both illuminate under test. The DETECTOR FAULT indicator will also illuminate if the selected loop loses power after the test switch is depressed. The airplane can be flown under master minimum equipment list procedures with the single-loop position selected for either the forward or aft compartments. The airplane operations manual will require the flight crew to perform these tests before the first flight each day to prevent detector faults from being unrecognized for more than one day.

3. **Procedure for Performing a Risk Assessment.**

Risk assessment consists of four general steps: Hazard Identification,

1. Evaluating relationship between exposure to a risk and adverse effects,
2. Exposure assessment - evaluating the conditions that lead to exposure to a risk,
3. Risk characterization - describe nature of adverse effects, their likelihood, and the strength of the evidence behind these characterizations (often done by using probability and statistics).

4. Point of Doing a Risk Assessment.

The risk assessment for a particular issue forms the foundation for making a decision about future actions. That decision may be to perform additional analyses, to perform activities that reduce the risk, or to do nothing at all.

5. Risk Management.

The process of combining a risk assessment with decisions on how to address that risk is called risk management. Risk management is part of a larger decision process that considers the technical and social aspects of the risk situation. Risk assessments are performed primarily for the purpose of providing information and insight to those who make decisions about how that risk should be managed. Judgment and values enter into risk assessment in the context of what techniques one should use to objectively describe and evaluate risk. Judgment and values enter into risk management in the context of what is the most effective and socially acceptable solution

6. The most common & combination detectors.

6.1 Heat detectors

Heat detectors are the oldest type of automatic fire detection device. They began development of automatic sprinklers in the 1860 seconds and have continued to the present with proliferation of various types of devices. A sprinkler can be considered a combined fire detection and extinguishing device.

Heat detectors that only initiate an alarm and have no extinguishing function are still in use. Although they have the lowest false alarm rate of all automatic fire detector devices, they also are the slowest in fire detecting. A heat detector is best situated for fire detection in a small confined space where rapidly building high-output fires are expected, in areas where ambient conditions would not allow the use of other fire detection devices, or when speed of detection is not prime consideration.

Heat detectors are generally located on or near the ceiling and respond to the convected thermal energy of a fire. They respond either when the detecting element reaches a predetermined fixed temperature or to a specified rate of temperature change. In general, heat detectors are designed to operate when heat causes a prescribed change in a physical or electrical property of a material or gas. Heat detectors can be sub-divide by their operating principles.

Heat detectors alone are not enough. They are suitable for areas in which, under normal operating conditions, smoke or similar aerosols may arise but where, in the event of a fire, an open, rapidly spreading flame can be expected.

6.2 Fixed Temperature Heat Detector.

Fixed-temperature heat detectors are designed to alarm when the temperature of the operating elements reaches a specific point. The air temperature at the time of alarm is usually considerably higher than the rated temperature because it takes time for the air to raise the temperature of the operating element to its set point. This condition is called thermal lag. Fixed-temperature heat detectors are available to cover a wide range of operating temperatures - from about 135 ^{O}F (57 ^{O}C) and higher. Higher temperatures detectors are also necessary so that detection can be provided in areas normally subject to high ambient temperatures, or in areas zoned so that only detectors in the immediate fire area operate.

- Fusible Element type
- Continuous type
- Bimetal type

6.3 Rate-of-Rise Detectors.

One effect that flaming fire has on the surrounding area is to rapidly increase air temperature in the space above the fire. Fixed-temperature heat detectors will not initiate an alarm until the air temperature near the ceiling exceeds the design operating point. The rate-of-rise detector, however, will function when the rate of temperature increase exceeds a predetermined value, typically around 12 to 15^{O}F (7 to 8^{O}C) per minute. Rate-of-rise detectors are designed to compensate for the normal changes in ambient temperature that are expected under non-fire conditions.

1) Line-type
2) Spot-type

6.4 Rate Compensation Detectors.

A rate compensation detector is a device that responds when the temperature of the surrounding air reaches a predetermined level, regardless of the rate of temperature rise.

A typical element is a spot-type detector with a tubular casing of metal that tends to expand lengthwise as it is heated, and an associated contact mechanism that will close at a certain point in the elongation. A second metallic element inside the tube exerts an opposing force on the contacts, tending to hold them open. The forces are balanced so that, with slow rate of temperature rise, there is more time for heat top penetrate to the inner element. This inhibits contact closure until the total device has been heated to its rated temperature level. However, with fast rate of temperature rise, there is less time for heat to penetrate to the inner element. The element therefore exerts less of an inhibiting effect, so contact closure is obtained when the total device has been heated to a lower level. This compensates for thermal lag. Thermal detectors using expanding metals are also automatically self-restoring after operation, when the ambient temperature drops to some point below the set point.

6.5 Combination detectors.

Combination detectors contain more than one element, which responds to fire. These detectors may be designed to respond from either element, or from the combined partial or complete response of both elements. An example of the former is a heat detector that operates on both the rate-of-raise and fixed-temperature principles. Its advantage is that the rate-of-rise element will respond quickly to rapidly developing fire, while the fixed-temperature element will respond to a slowly developing fire when the detecting element reaches its set point temperature. The most common combination detector uses a vented air chamber and a flexible diaphragm for the rate-of-rise function, while the fixed-temperature element is usually leaf spring restrained by a eutectic metal FIGURE. When the fixed-temperature element reaches its design operating temperature, the eutectic metal fuses and releases the spring, which closes the contact.

6.6 Electronic Spot-type Thermal sensor.

A thermoelectric effect detector is a device that utilizes a sensing element consisting of one or more thermostats, which produce a change in electrical resistance in response to an increase in temperature FIGURE. This resistance change is monitored by an associated electronic circuitry, and the detector responds when the resistance changes at an abnormal rate (rate-of-rise type) or when the resistance reaches a specific value (fixed-temperature type).

Rate-of-rise detectors of this type use two thermostats. One is exposed to changes in atmospheric temperatures. When the temperature rapidly changes as in fire situation, the temperature of the exposed thermostat increases faster than the temperature of the unexposed reference thermostat, generating a net change in resistance causing the detector to go into alarm condition. Most rate-of-rise detectors are designed with fixed-temperature backup feature so that, should the temperature rise be slower than 15^{O}F per min, the detector will operate when the exposed thermostat has reached a predetermined fixed temperature.

6.7 Flame Detection.

A flame detector responds either to radiant energy visible to the human eye (approx. 4000 to 7700) or outside the range of human vision. Similar to the human eye, flame detectors have a 'cone of vision', or viewing angle, that defines the effective detection capability of the detector.

With this constraint, the sensitivity increases as the angle of incidence decreases. Such a detector is sensitive to glowing embers, coals, or flames, which radiate energy of sufficient intensity and spectral quality to actuate the alarm. Each type of fuel, when burning, produces a flame with specific radiation characteristics. A flame detection system must be chosen for the type of fire that is probable. For example an ultraviolet (UV) detector will respond to a hydrogen fire, but an infrared (IR) detector operating in the 4.4-micron sensitivity range will not. FIGURE it is imperative, therefore, that a qualified fire protection engineer be involved in the design of these systems, along with assistance from the manufacturer's design staff. Involved in the design of these systems, along with assistance from the manufacturer's design staff.

Due to their fast detection capabilities, flame detectors are generally used only in high-hazard areas, such as fuel-loading platforms, industrial process areas, hyperbaric chambers, high-ceiling areas, and atmospheres in which explosions or very rapid fires may occur. Because flame detectors must be able to 'see' the fire, they must not be blocked by objects placed in front of them. The infrared-type detector, however, has some capability for detecting radiation reflected from walls.

6.8 UV Flame Detectors.

Ultraviolet (UV) detectors generally use either a solid-state device, such as silicone carbide or aluminum nitride, or a gas-filled tube as the sensing element. UV detectors are essentially sensitive to both, sunlight and artificial light. A UV flame radiates in the 1850 to 2450 angstrom range. Virtually all fire emits radiation in this band, while the sun's radiation at this band is absorbed by the Earth's atmosphere. The result is that the UV detector is solar blind, meaning it will not cause an alarm in response to radiation from the sun. The implication of this feature is that it can easily be used both indoors and outdoors.

UV detectors are sensitive to most fires, including hydrocarbon, metals, sulfur, hydrogen, hydrazine, and ammonia. Arc welding, electrical arcs, lightning, X-rays used in nondestructive metal testing equipment, and radioactive materials can produce levels that will activate a UV detection system. The presence of UV-absorbing gases and vapors will attenuate the UV radiation from a fire, adversely affecting the ability of the detector to 'see' a flame. Likewise, the presence of an oil mist in the air or an oil film on the detector window will have the same effect.

6.9 UV/IR Flame Detector.

An ultraviolet/infrared flame detector consists of an UV and single-frequency sensor, paired together to form one unit. The two sensors individually operate the same as described in the UV and IR sections, but additional circuitry processes signals from both sensors. A fire alarm is produced only when both sensors detect a fire. The result is that a UV/IR system has better false alarm rejection capabilities than either detector by itself. Since the UV/IR detector pairs two sensor types, it is subject to the limitation of both.

6.10 Optical fire detectors.

Optical smoke detectors cannot detect invisible aerosol particles of the type produced by open wood fires, for example. They are therefore unsuitable for use as solitary detectors where such fires can occur.

6.11 Ionization.

The ionization smoke detector is the only detector that can register invisible fire aerosols as well as fine, dark aerosols. However, in order to do so, the aerosol particles must be neutral and not too big. The means of intensity is obtained from the equation ;

$$I/Io = Exp^{-kl}$$

The process of gas analyzers recorded CO, CO_2 that analysis according to, and water content in the air from samples drawn from the test section. The instrument ranges are $0.5 \times I^{0.4}$ lumen fraction CO and 0 to 0.04 volume fraction of CO_2.The uncertainty of the measurements is stated as 2.5×10^{-6} volume fractions CO and 2×10^{-5} volume fractions CO_2. The water analyzer range is 0-0.05 volume fractions with an expanded uncertainty of 10 % of the measurement.

7. Development of System Fault Trees.

Once component failure rates were developed, system schematics were used to develop fault trees for individual systems. Figure 15 provides a summarized version of the fault tree design.

The fault tree structures were programmed into spreadsheets. The spreadsheet programs allowed failure probability and reliability information to be propagated through the systems using the fault tree models, resulting in an overall system reliability estimate.

Once the baseline system reliability information was obtained, further analysis was performed to examine testing and inspection intervals and how altering these intervals affected the system's reliability. The use of fault trees provided information that offers insight into testing and inspection frequencies and established a means to track system performance. The detection system must provide a visual indication to the flight crew within one minute after the start of the fire.

- False Warning are mainly caused by the freight or specific environmental conditions within the cargo holds

- With the 60 sec detection time requirement (FAR/JAR 25.858), the system design is always a compromise between fast detection and signal reliability all those are result from the development of System Fault Trees Analysis. System design and components location as figures below.

Figure 30 A Pair of Smoke Detector Position

Source: Meeting in Phoenix AZ on March 26-27th, 2003

Figure 31 A Pair of Smoke Detector Installed

Source: Meeting in Phoenix AZ on March 26-27th, 2003

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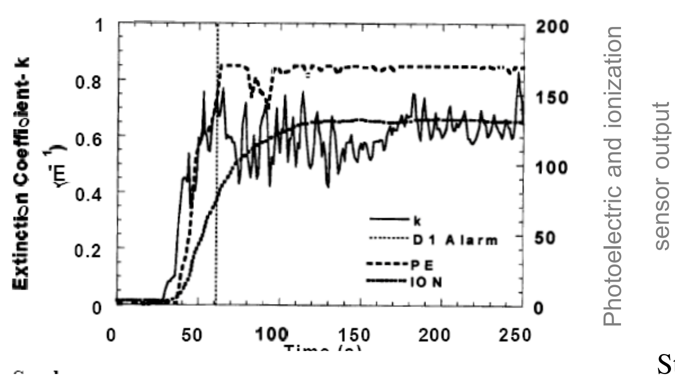
APPENDICES

Appendix A

Experiment/Testing

Test fire 1, the flaming fire, emulates conditions developed as the result of a burgeoning hydrocarbon pool or burning plastics fire. The FE/DE (figure.1) reproduced the flow conditions by control of the fan speed to achieve the expected ceiling jet velocity. The heater set point was controlled to provide the increasing temperature at the detector location. Smoke was provided from the propane smoke generator attached to the FE/DE. The smoke generator **is** an annular co-flowing, aid propane diffusion burner contained in a steel duct with damper-controlled bypass and tunnel connections. The fan speed was set at 10 *Hz, which* yielded a mean core flow of 0.25 m/ s at the test section. The damper was opened at time = 0 to let smoke flow into the duct.

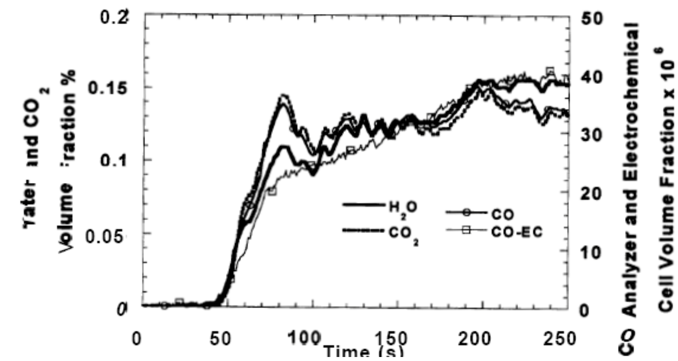
Figures A1-A3 show representative values of smoke extinction, combustion gases and air temperature for this scenario. The alarm time for the spot-type aircraft detector is marked on the extinction graph; the draw-through detector did not record an alarm. In Figure A1, the extinction coefficient began to rise at 30 seconds, (this delay represents the transport of the smoke from the smoke generator to the test section). At about 40 seconds, both the photoelectric and ionization analog signals began to rise. The photoelectric signal reached its maximum output at 60 seconds while the ionization signal continued to climb until leveling off at 120 seconds. The ionization signal lagged the extinction value due to the smoke entry lag of the detector. Figure A2 shows CO, CO_2 and water volume fractions with background values subtracted.



Started at time = 0

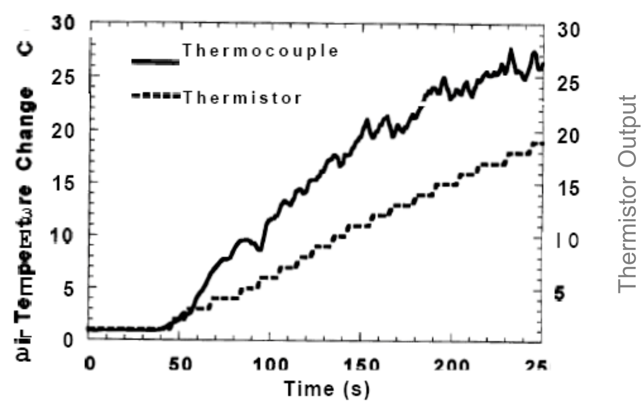
Appendix Figure A1 Smoke Level for Test Fire 1, Flaming Fire Shows CO, CO_2, and Water Volume Fractions with Background Values Subtracted.

Source: National Institute Of' Standards and Technology Gaithersburg, Maryland U.S.A., 2001



Started at time = 0

Appendix Figure A2 Gas Signatures for Test Fire 1, Flaming Fire.
Source: National Institute Of' Standards and Technology Gaithersburg,
Maryland U.S.A., 2001



Started at time = 0

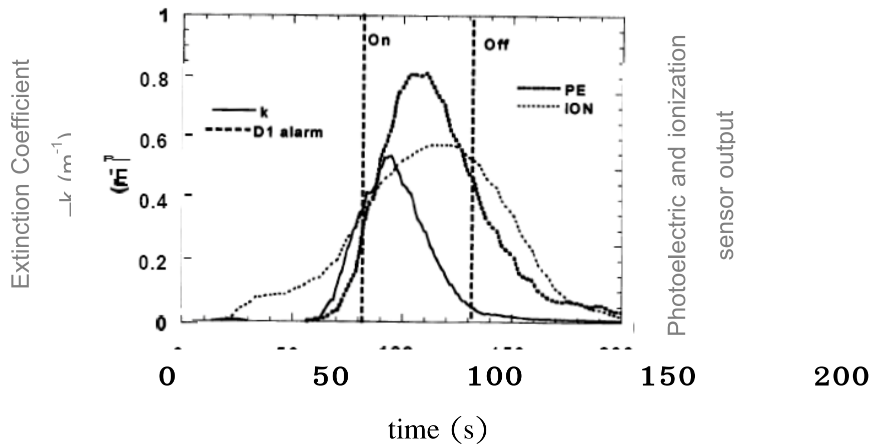
Appendix Figure A3 Temperature Rise for Test Fire 1, Flaming Fire 63
Source: National Institute Of' Standards and Technology Gaithersburg,
Maryland U.S.A., 2001.

All gas concentrations began to rise at 45 seconds (time to transport gases to analyzers = 15 seconds). The delayed response of the electrochemical cell is most likely due to diffusion transport delay of CO into the cell itself. The $C0_2$ and water volume fractions are nearly identical which would be expected from nearly complete combustion of propane. The CO/CO_2 volume ratio is about 0.025, which is reasonable for the over-ventilated diffusion flame in the smoke generator. The temperature rate of rise averaged 0.13 $^{o}C/s$ from 40 seconds to 250 seconds (Figure A3). The thermistor output lagged the fast-response thermocouple. This is a constant occurrence due to the relatively sluggish response characteristics of the thermostat compared to the fast-response thermocouple.

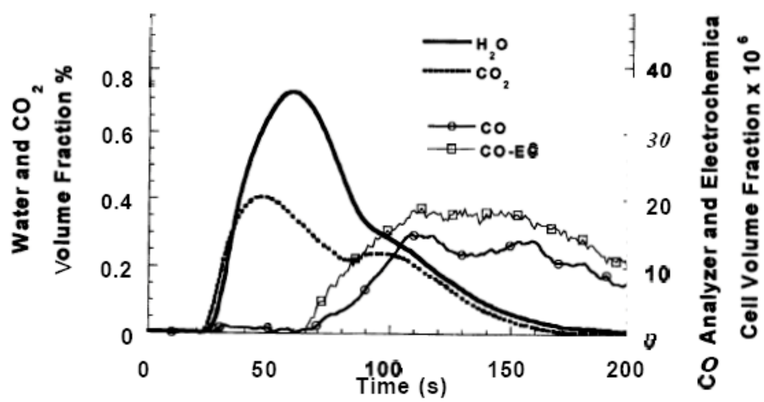
Will continue on test fire 2, test fire 3 and more about the low- smoke flaming fire by ignition of alcohol-soaked baggage, the smoldering cotton fire source, they will indicate or show representative smoke, combustion gas production and temperature rise from this scenario.

Test fire 2, the low-smoke flaming fire was designed to emulate conditions from a cargo compartment fire that begins by ignition of alcohol-soaked baggage where the initial effluent is very low smoke until the alcohol burns out and the fabric starts to burns. The result is a temperature rises and gas signature that precedes the measurable smoke at the test section. The fuel consisted of six 7 cm diameter cotton polyester (50/50 blend by weight) fabric circles stacked and held together with 3 staples, and wetted with 5 ml. of ethanol. The wetted fabric was placed over a 10 cm glass dish and supported by two crisscrossed Ni-Chrome wires, then placed at the bottom of the vertical riser section of the FE/DE prior to ignition. The fan speed was set to 10 Hz (mean flow velocity of 0.25 m /s), then the alcohol was ignited at time = 0. At first, only the alcohol burned as it was wicked through the fabric or burned from excess in the dish below. During this phase, no appreciable smoke was produced. As the alcohol burned out, the fabric circles caught fire and burned with considerable smoke production, then burned out.
Figure A4, A6 shows representative smoke, combustion gas production and temperature rise from this scenario. In figure A4 the ionization signal started to rise at 20 s while the extinction and photoelectric signal started to rise at 60 seconds. The initial combustion produced an aerosol that was not scattering much light, but was being sensed by the ionization detector. As the fabric circles caught fire, the extinction coefficient and photoelectric signals began to rise. The extinction coefficient decayed much faster than the photoelectric or ionization signal due to hold-up of the heated smoke in the detector sensing volume.

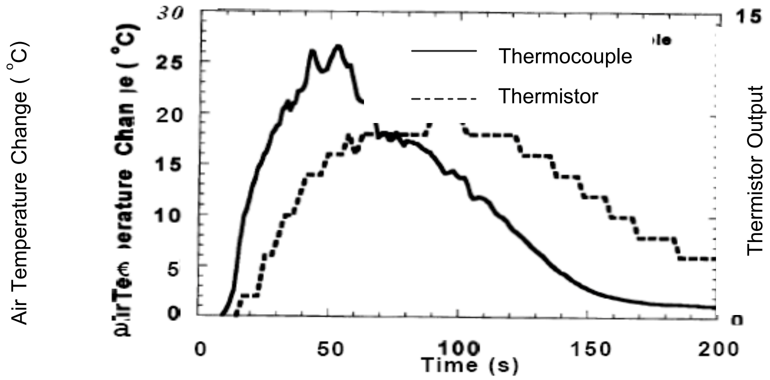
Figure A5 shows CO, CO_2, and water volume fraction with background values subtracted. At 25 seconds water and CO_2 started to rise; initially, water was higher than the CO_2, which is expected.



Appendix Figure A4 Smoke Level for Test Fire 2, Alcohol-Soaked Fabric Fire.
Source: National Institute Of' Standards and Technology Gaithersburg,
Maryland U.S.A., 2001



Appendix Figure A5 Gas Signatures for Test Fire 2, Alcohol-Soaked Fabric Fire
Source; National Institute Of' Standards and Technology Gaithersburg, Maryland U.S.A., 2001

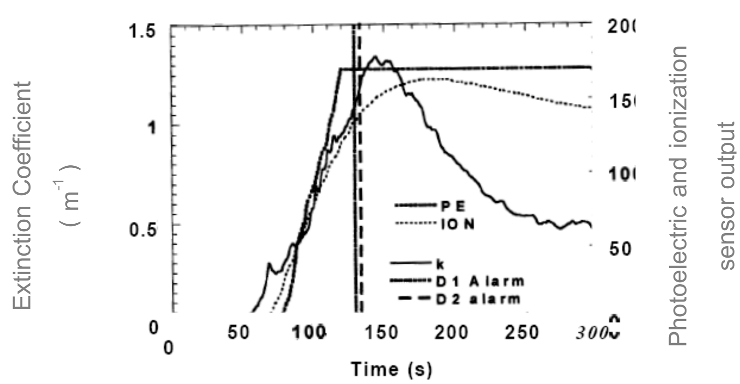


Appendix Figure A6 Temperature Rise for Test Fire 2, Alcohol-Soaked Fabric Fire. Source: National Institute Of' Standards and Technology Gaithersburg, Maryland U.S.A., 2001

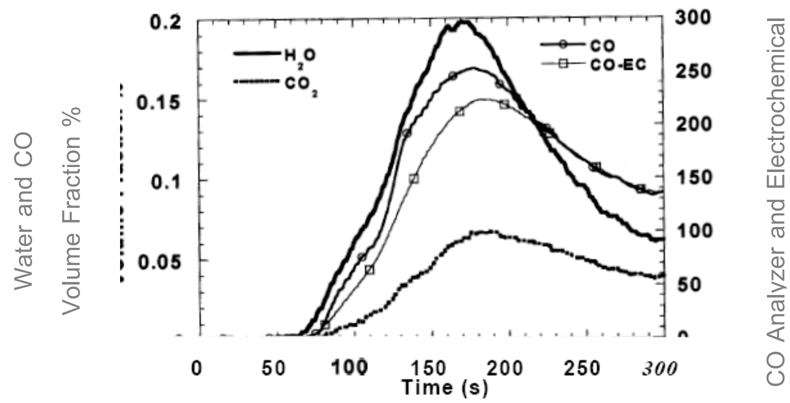
As the ethanol was burning, The CO concentration began to rise as the fabric started to burn and remained elevated even as the extinction decreased to near zero. The output of the electrochemical cell deviated from the CO analyzer and was most likely due to temperature and humidity effects of the cell output. Air temperature rose at a rate of nearly 1°C /s, peaking at 27°C above ambient (~ 2 0°C) 30 seconds after the initial rise (figure A6).

Test fire 3, the smoldering cotton fire source, is a variant of a initial rise standard detector sensitivity test fire EN 54 part 9 test fire 3. A staged-wick-ignition test fixture developed for use in the FE/DE holds 32 cotton wicks 6 mm in diameter (typically 15 cm long) in a vertical orientation around a circular frame. Unique to the test fixture developed here is that each wick pair is spaced so that it is 5 cm. away from adjacent pairs and the bottom of each wick passes through a wound ni-chrome ignition wire. Opposing pairs are wired in series producing a maximum of 8 independently ignited sets of 4 wicks. For the tests here, the objective was to produce a steadily increasing smoke concentration at the test section for 120 seconds. This was accomplished by igniting 8 sets of 4 wicks with a 12 seconds delay between each set. The fan was set to 10 Hi, yielding a mean velocity of 0.25 m/s at the test section, and the ignition sequence was started at time = 0. Figures A7 and A8 show representative smoke and combustion gas production for this source. In Figure A8, the extinction started to rise at 50 seconds. and followed by the ionization signal at 60 seconds and the photoelectric signal at 70 seconds. The photoelectric signal reached its maximum output at 115 sec and both of the aircraft detectors alarmed between 130 sec and 135 sec. The extinction coefficient peaked at 140 seconds. In Figure A8, the gas concentrations began to rise between 60 s and 70 sec, and peaked at about 170 seconds. The CO/CO_2 volume ratio is about 1:2.6, similar to the 1:3 ratio obtained in room tests with the same cotton smolder source. The CO_2/water volume ratio is approximately 1:3. Air temperature rise peaked at 3.5 ^{O}C which is not uncharacteristic for low-energy-output smolder plumes.

Test fire 4, pyrolyzing mixed plastics, uses the same smolder source being developed at the FAA Technical Center. It consisted of a 10 cm. by 10 cm. by 0.5 cm. plaque of compressed plastic pellets, 2 mm to 5 mm. in size with a Ni-Chrome wire embedded in it. The pellets were a mix of various plastics. The plaque was placed at the bottom of the vertical riser. The fan speed was set to 10 *Hz* yielding a mean flow velocity of 0.25 m/s at the test section. At time = 0, 40 volts AC power was applied to the ni-chrome wire which was sufficient to start the plastics to pyrolyze and emit smoke and gases.

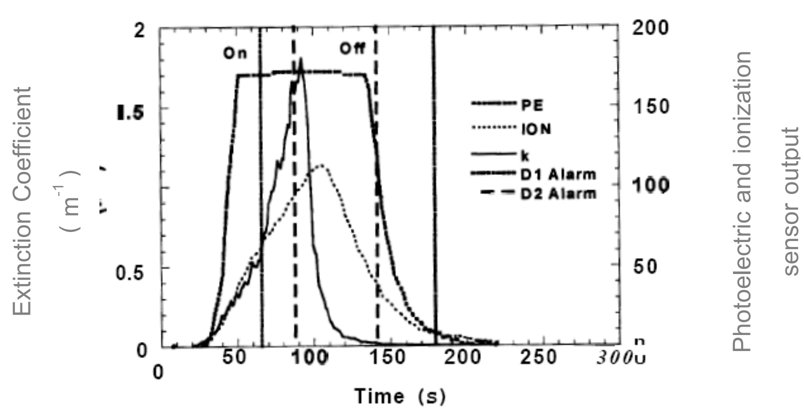


Appendix Figure A7 Smoke Level for Test Fire 3, Smoldering Cotton Wicks.
Source: National Institute Of' Standards and Technology Gaithersburg, Maryland U.S.A., 2001

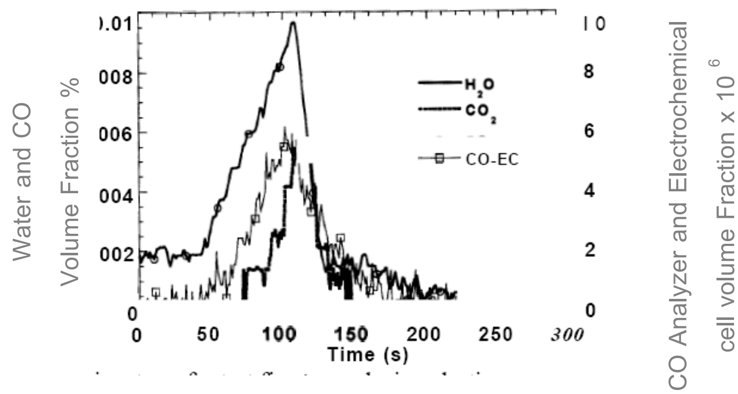


Appendix Figure A8 Gas Signatures for Test Fire 3, Smoldering Cotton Wicks.
Source: National Institute Of' Standards and Technology Gaithersburg,
Maryland U.S.A., 2001

The power was removed at 80 seconds and the pyrolyzing eventually stopped. Next figures 9 and 10 show representative smoke and combustion gas production for this source. The photoelectric, ionization signal, and extinction coefficient all began to rise at 30 seconds. The photoelectric signal reached its maximum output at 50 seconds while the extinction coefficient and ionization signal continued to rise peaking at 90 seconds and 105 seconds respectively. The spot type aircraft detector alarmed at 66 seconds, while the draw-through detector alarmed at 88 seconds. The combustion gas production levels were low compared to the other smolder sources.

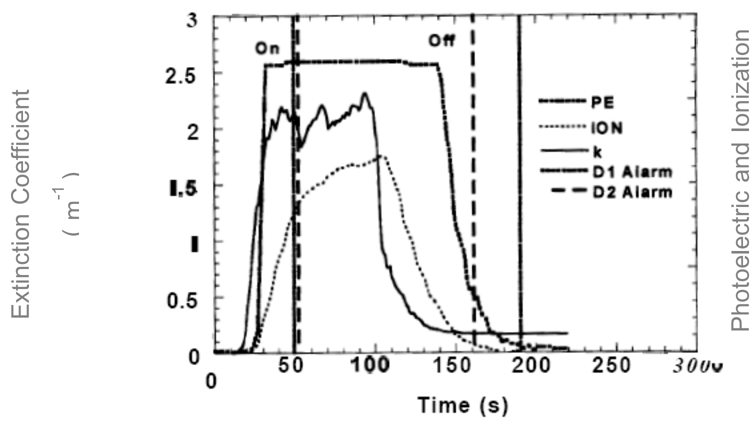


Appendix Figure A9 Smoke Level for Test Fire 4, Pyrolyzing Plastics.
Source: National Institute Of' Standards and Technology Gaithersburg,
Maryland U.S.A., 2001



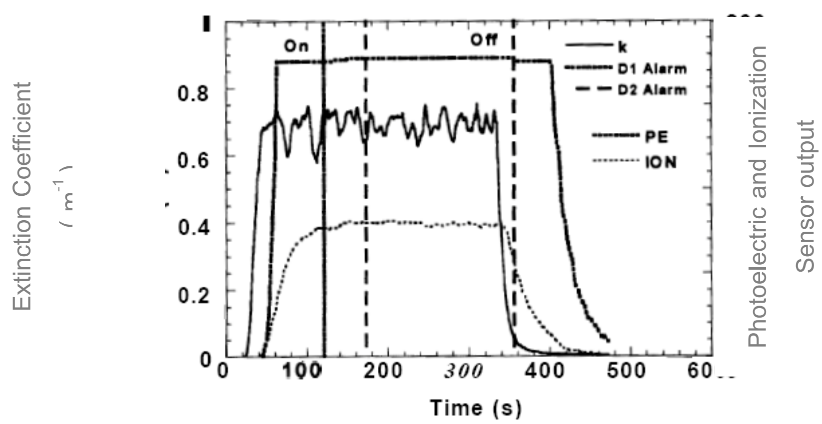
Appendix Figure A10 Gas Signatures for Test Fire 4, Pyrolyzing Plastics.
Source: National Institute Of' Standards and Technology Gaithersburg,
Maryland U.S.A., 2001

The CO volume fraction peaked at 6 % while the CO_2 volume fraction peaked at $5.0x10^{-3}$ % above the background level. No rise in the water concentration was observed. Air temperature rise was about 1 ^{o}C above ambient temperature. Injecting IS0 12103-1 fine grade Arizona test dust at a constant rate from a powder screw feeder generated the dust aerosol. With the fan speed set at 10 *Hz,* the dust was fed into the duct at time = 0. Figure A11 shows the extinction coefficient and Detector output for this source. The extinction coefficient started to rise at about 12 seconds followed by the photoelectric and ionization signals 10 seconds. later. The extinction was above 2 m^{-1} at 30 seconds and stayed between 2 m^{-1} and 2.5 m^{-1} until the dust flow was stopped at 100sec. and the remaining dust blown out of the duct. The photoelectric signal reached its maximum output at about 25seconds, while the ionization continued to rise until the dust flow was stopped. The spot-type aircraft detector alarmed at 59seconds, while the draw-through detector alarmed at 100 seconds. The oil mist aerosol was generated by nebulizing cooking oil from a bank of 10 medical inhalent nebulizers located at the bottom of the vertical riser of the FE/DE. This aerosol is a surrogate for hydraulic oil or non-volatile mists introduced in a cargo compartment intentionally (cargo treatment) or unintentionally. The fan speed was set at 7 Hz yielding at mean flow velocity of 0.15 m/s at the test section, and the nebulizers were started at time = 0. Figure A12 shows the extinction coefficient and detector outputs for this source. The extinction coefficient started to rise at 20 seconds and reached nearly steady values between 0.6 m-' and 0.7 m-' within 10 s. The photoelectric and ionization signals began to rise at 40 s with the photoelectric signal saturating at about 60 seconds while the ionization signal continued to rise until reaching a steady value at approximately 120 seconds. The spot-type aircraft detector alarmed at 120 seconds, while the draw-through detector alarmed at 173 seconds.



Appendix Figure A11 Particulate Level for Nuisance Source 1, Dust Exposure. Analysis Link

Source: National Institute Of' Standards and Technology Gaithersburg, Maryland U.S.A., 2001



Started at time = 0.

Appendix Figure A12 Particulate Level for Nuisance Source 2,Oil Mist Wxposure.

Source: National Institute Of' Standards and Technology Gaithersburg, Maryland U.S.A., 2001

Conclusions

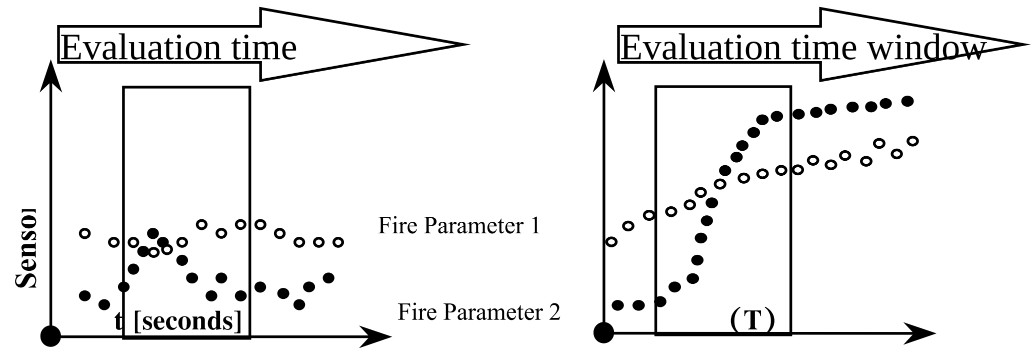
Six plausible fire and nuisance alarm scenarios for aircraft cargo compartments were reproduced in the FE/DE. The data gathered contains particulate, combustion gas and temperature rise values that may be used to identify sensor combinations to discriminate between fire and non-fire conditions. Background levels of particulate, combustion gas and temperature fluctuations need to be included in any analysis leading to sensor selection and alarm algorithm design.

Source; 12Th International Conference on Automatic Fire Detection Maryland U.S.A., 2001.

Some fire and non fire scenario are presented here-below as possible development tests for fire detection system.

Appendix Table A1 Fire and Non – Fire Scenario

Fire cases • Open cellulosic fire (wood) : EN 54- TF1 [5] • Smouldering pyrolysis fire (wood): EN 54 - TF2 • Glowing Smouldering fire (cotton) : EN 54 - TF3 • Open plastics fire (polyurethane) :EN 54 - TF4 • Liquid fire (N-Heptane) : EN 54 -TF5 • Liquid fire (Methylated spirits) :EN 54 - TF6 • Paper (UL268) : - Paper towels (open) - Scheduled newspapers (open) - Normal newspapers (open) - Normal newspapers (Smouldering) **Non fire cases :** • Moisture • Condensation • Fog • Sand and Dust	------- • Cardboard boxes : - Open cardboard fire - Smouldering cardboard fire • Textile : - 60 % Wool / 40 % Acrylic (open) - 60 % Wool / 40 % Acrylic (Smouldering) - 100 % cotton (open) - 100 % cotton (Smouldering) - 100 % polyester (open) - 100 % polyester (Smouldering) - 100 % wool (open) - 100 % wool (Smouldering) • Jet A fuel fire • Diesel fire • Oil fire • Cable fire -------- • Fruit / Animals / Vegetables • Oil • Exhaust gas



Appendix Figure A13 Non-Fire & Fire Case.

Non - fire case:

Several Parameters (e.g. radiation, dust, gases) vary due to environmental conditions

Fire case

Parameters develop typically. In Multi sensors, Signals are over a certain period of time

Delphi sort codes summary

The lowest order algorithm to solve a problem, we will not know exactly how much time is required to obtain a solution, but we will know that as the problem size increases, there will always exist appoint is beyond which the lowest order method will take less time than higher order Delphi algorithm. Figures page 51,52 and 53 are just demonstrate this behavior, algorithms whose running time are $t = n$, $t = 1/2\ n^2$, and $t = n^2$ respectively.

```
var
 lRC1, lRC2, lRC3, lRC4,
 lCC1, lCC2, lCC3, lCC4
 : Boolean;

procedure TfrmFASystem.psbExitClick(Sender: TObject);
begin
 frmFASystem.Close;
end;

procedure TfrmFASystem.psbPrintClick(Sender: TObject);
begin
 frpSWGroup.ShowReport;
end;

procedure TfrmFASystem.bbtSEQNameClick(Sender: TObject);
var
 cSearch
 : String;
begin
 cSearch := '%' + edtEQName.Text + '%';

 with qryEquip do begin
  Close;
  SQL.Clear;
  SQL.Add('select * from Equip');
  SQL.Add('where (EQName like ''' + cSearch + ''')');
  Open;
 end;
end;
```

```
procedure TfrmFASystem.bbtAEquipClick(Sender: TObject);
var
 nItemNo
 : Integer;
 cKey, cItemNo
 : String;
begin
 cKey := qryEquip.FieldByName('EQID').AsString;
 with tabFAItem do begin
  if Eof then begin
   cItemNo := '01';
  end else begin
   Last;
   cItemNo := FieldByName('ItemNo').AsString;
   nItemNo := StrToInt(cItemNo) + 1;
   if (nItemNo < 10) then begin
    cItemNo := '0' + IntToStr(nItemNo);
   end else if (nItemNo < 100) then begin
    cItemNo := IntToStr(nItemNo);
   end else begin
    cItemNo := '**';
   end;
  end;
  Append;
  FieldByName('ItemNo').AsString := cItemNo;
  FieldByName('EQID').AsString := cKey;
  FieldByName('EQName').AsString
  := qryEquip.FieldByName('EQName').AsString;
  FieldByName('R').AsFloat
  := qryEquip.FieldByName('R').AsFloat;
```

(continued)

```
    FieldByName('Q').AsFloat
   := qryEquip.FieldByName('Q').AsFloat;
   FieldByName('QtyEQ').AsInteger := 1;
   FieldByName('UCost').AsFloat
   := qryEquip.FieldByName('UCost').AsFloat;
   FieldByName('TCost1').AsFloat
   := qryEquip.FieldByName('UCost').AsFloat;
   Post;
  end;
  qryEquip.Next;
  tshPage1.Show;
end;
procedure TfrmFASystem.btnRC1Click(Sender: TObject);
var
 cFANo
 : String;
 nR
 : Real;
begin
 chtReliability.Series[0].Clear;
 if lRC1 then begin
  lRC1 := False;
  Exit;
 end;
 lRC1 := True;
 with tabFASystem do begin
  First;
```

(continued)

```
  while not Eof do begin
   cFANo := FieldByName('fANo').AsString;
   nR := FieldByName('R1').AsFloat;
   chtReliability.Series[0].Add(nR, cFANo);
   Next;
  end;
 end;
end;
procedure TfrmFASystem.bbtCalcClick(Sender: TObject);
var
 nQtyEQ, i
 : Integer;
 nUCost,
 nR, nQ,
 nF,
 nTCost1,
 nTCost2,
 nTCost3,
 nTCost4,
 nR1, nCostT11,
 nR2, nCostT12,
 nR3, nCostT13,
 nR4, nCostT14,
 nQ1, nCostT21,
 nQ2, nCostT22,
 nQ3, nCostT23,
 nQ4, nCostT24
```

(continued)

```
: Real;
begin
 with tabFAItem do begin
  First;
  while not Eof do begin
   nQtyEQ := FieldByName('QtyEQ').AsInteger;
   nUCost := FieldByName('UCost').AsFloat;
   Edit;
   FieldByName('TCost1').AsFloat := nQtyEQ * nUCost;
   FieldByName('TCost2').AsFloat := 2* nQtyEQ * nUCost;
   FieldByName('TCost3').AsFloat := 3* nQtyEQ * nUCost;
   FieldByName('TCost4').AsFloat := 4* nQtyEQ * nUCost;
   Post;
   nR := FieldByName('R').AsFloat;
   nF := 1.00;
   for i := 1 to nQtyEQ do begin
    nF := nF * (1.00 - nR);
   end;
   nR := 1.00 - nF;
   Edit;
   FieldByName('R1').AsFloat := nR;
   Post;
   for i := 1 to nQtyEQ do begin
    nF := nF * (1.00 - nR);
   end;
   nR := 1.00 - nF;
```

(continued)

```
 Edit;
 FieldByName('R2').AsFloat :=
nR;
 Post;
 for i := 1 to nQtyEQ do begin
  nF := nF * (1.00 - nR);
 end;
 nR := 1.00 - nF;
 Edit;
 FieldByName('R3').AsFloat :=
nR;
 Post;
 for i := 1 to nQtyEQ do begin
  nF := nF * (1.00 - nR);
 end;
 nR := 1.00 - nF;
 Edit;
 FieldByName('R4').AsFloat :=
nR;
 Post;
 nQ := FieldByName('Q').AsFloat;
 nF := 1.00;
 for i := 1 to nQtyEQ do begin
  nF := nF * nQ;
 end;
 nQ := nF;
```

(continued)

```
Edit;
FieldByName('Q1').AsFloat := nQ;
Post;
for i := 1 to nQtyEQ do begin
 nF := nF * nQ;
end;
nQ := nF;
Edit;
FieldByName('Q2').AsFloat := nQ;
Post;
for i := 1 to nQtyEQ do begin
 nF := nF * nQ;
end;
nQ := nF;
Edit;
FieldByName('Q3').AsFloat := nQ;
Post;
for i := 1 to nQtyEQ do begin
 nF := nF * nQ;
end;
nQ := nF;
Edit;
FieldByName('Q4').AsFloat := nQ;
Post;

Next;
```

(continued)

```
cItemNo;
 FieldByName('EQID').AsString := cKey;
 FieldByName('EQName').AsString
 := qryEquip.FieldByName('EQName').AsString;
 FieldByName('R').AsFloat
 := qryEquip.FieldByName('R').AsFloat;
 end;
 nTCost1 := 0.00;
 nTCost2 := 0.00;
 nTCost3 := 0.00;
 nTCost4 := 0.00;
 nR1 := 1.00;
 nR2 := 1.00;
 nR3 := 1.00;
 nR4 := 1.00;
 nQ1 := 1.00;
 nQ2 := 1.00;
 nQ3 := 1.00;
 nQ4 := 1.00;
 First;
 while not Eof do begin
  nTCost1 := nTCost1 + FieldByName('TCost1').AsFloat;
  nTCost2 := nTCost2 + FieldByName('TCost2').AsFloat;
  nTCost3 := nTCost3 + FieldByName('TCost3').AsFloat;
  nTCost4 := nTCost4 + FieldByName('TCost4').AsFloat;
  nR1 := nR1 * FieldByName('R1').AsFloat;
```

(continued)

```
 nR2 := nR2 * FieldByName('R2').AsFloat;
 nR3 := nR3 * FieldByName('R3').AsFloat;
 nR4 := nR4 * FieldByName('R4').AsFloat;
 nQ1 := nQ1 * (1.00 - FieldByName('Q1').AsFloat);
 nQ2 := nQ2 * (1.00 - FieldByName('Q2').AsFloat);
 nQ3 := nQ3 * (1.00 - FieldByName('Q3').AsFloat);
 nQ4 := nQ4 * (1.00 - FieldByName('Q4').AsFloat);
 Next;
end;
end;
with tabFASystem do begin
 Edit;
 FieldByName('TCost1').AsString := Format('%7.2f', [nTCost1]);
 FieldByName('TCost2').AsString := Format('%7.2f', [nTCost2]);
 FieldByName('TCost3').AsString := Format('%7.2f', [nTCost3]);
 FieldByName('TCost4').AsString := Format('%7.2f', [nTCost4]);
 FieldByName('R1').AsString := Format('%7.6f', [nR1]);
 nCostT11 := (1.00 - nR1) * tabAirPlane.FieldByName('CostT1').AsFloat;
 FieldByName('CostT11').AsString := Format('%10.2f', [nCostT11]);

 FieldByName('R2').AsString := Format('%7.6f', [nR2]);
 nCostT12 := (1.00 - nR2) * tabAirPlane.FieldByName('CostT1').AsFloat;
 FieldByName('CostT12').AsString := Format('%10.2f', [nCostT12]);

 FieldByName('R3').AsString := Format('%7.6f', [nR3]);
 nCostT13 := (1.00 - nR3) * tabAirPlane.FieldByName('CostT1').AsFloat;
 FieldByName('CostT13').AsString := Format('%10.2f', [nCostT13]);
```

(continued)

```
   FieldByName('R4').AsString := Format('%7.6f', [nR4]);
  nCostT14 := (1.00 - nR4) * tabAirPlane.FieldByName('CostT1').AsFloat;
  FieldByName('CostT14').AsString := Format('%10.2f', [nCostT14]);
  FieldByName('Q1').AsString := Format('%7.6f', [1.00 - nQ1]);
  nCostT21 := (nQ1) * tabAirPlane.FieldByName('CostT2').AsFloat;
  FieldByName('CostT21').AsString := Format('%10.2f', [nCostT21]);
  FieldByName('Q2').AsString := Format('%7.6f', [1.00 - nQ2]);
  nCostT21 := (nQ2) * tabAirPlane.FieldByName('CostT2').AsFloat;
  FieldByName('CostT22').AsString := Format('%10.2f', [nCostT22]);
  FieldByName('Q3').AsString := Format('%7.6f', [1.00 - nQ3]);
  nCostT21 := (nQ3) * tabAirPlane.FieldByName('CostT2').AsFloat;
  FieldByName('CostT23').AsString := Format('%10.2f', [nCostT23]);
  FieldByName('Q4').AsString := Format('%7.6f', [1.00 - nQ4]);
  nCostT21 := (nQ4) * tabAirPlane.FieldByName('CostT2').AsFloat;
 FieldByName('CostT24').AsString := Format('%10.2f', [nCostT24]);
  Post;
 end;
end;

procedure TfrmFASystem.btnDFAItemClick(Sender: TObject);
begin
 tabFAItem.Delete;
end;

procedure TfrmFASystem.btnCC1Click(Sender: TObject);
var
 cFANo
```

(continued)

```
 : String;
 nTCost
 : Real;
begin
 chtCost.Series[0].Clear;
 if lCC1 then begin
  lCC1 := False;
  Exit;
 end;
 lCC1 := True;
 with tabFASystem do begin
  First;
  while not Eof do begin
   cFANo := FieldByName('fANo').AsString;
   nTCost := FieldByName('TCost1').AsFloat;
   chtCost.Series[0].Add(nTCost, cFANo);
   Next;
  end;
 end;
end;
procedure TfrmFASystem.btnRC2Click(Sender: TObject);
var
 cFANo
 : String;
 nR
 : Real;
begin
 chtReliability.Series[1].Clear;
```

Probable environmental conditions at the time of fire alarm case events

Event 1: Description

Physical parameter	Temp	Humid/ Condense	Radius	Combust Aerosols	Other Aerosols	Comb gases	Other gases
Probable level	Low	Low	Low	Low	Medium	Low	High

Analysis of fire alarm cases

Date: 23/10/1998

Source: AIRBUS (extract)

Aircraft Make: AIRBUS A-340

Carrier: SABENA

Phase Flight: TAKE OFF

Narrative: At 4000 ft with configuration 1 forward cargo smoke red alarm came on. According to Emergency Procedures the forward cargo cooling was switched off. The switch was pre in max. One minute later the alarm went out. Visual check performed and confirmed neither smoke nor fire in the fwd compartment. Flight was continued. During cruise at flight level 290 lavatory smoke warning came on. Toilet g1 triggered this alarm a lot of times. Visual confirmed nobody inside the toilet and no smoke evidence. Action: maintenance inspected fwd cargo and lavatory and did not find any indicator of fire or smoke. Investigation related to oil smell in cabin revealed 3 oil quantity lower than on other engines. Suspected oil suction to air system. Deactivated engine 3 bleed system switch SDCU and smoke detector test were satisfactory. The next flights were also performed with engine 3 bleed off and oil consumption was monitored and found within limits. On ground in BRU when switching APU bleed on smoke appeared in cabin, cockpit. Smoke disappeared after switching off pack 2. Smoke did not generate with pack 2 on afterwards. Problems suspected to come from APU pneumatic duct. Maintenance found oil leak on filter bowl. O-ring replaced and leak check performed. Engine 3 bleed system was reactivated.

Event 2: Description

Physical parameter	Temp	Humid/ Condense	Radius	Combust Aerosols	Other Aerosols	Comb gases	Other gases
Probable level	High	Low	Medium or High	High	Medium or Low	High	Low

Analysis of typical false alarm cases

Date: 21/11/1985

Source: CAA (extract)

Aircraft Make: BOEING B-747

Carried: NOT REPORTED

Phase Flight: CRUISE

Narrative: Lower aft cargo hold fire warning. A/c diverted emergency evacuation. False fire warning, following a lower aft cargo hold fire warning a/c diverted to LAJES where an emergency evacuation was effected. Some difficulty due to excessive force needed to open fully doors 2 & 4 LH. & 2 & 5RH. Several passengers sustained minor injuries. The cause of the fire warning was attributed to condensation emanating from a considerable quantity of 'warm' fruit. The two detectors were slightly oversensitive but this is considered a very minor contributory factor. A mod has been initiated to fit a dual loop smoke detector system.

Event 3: Description

Physical parameter	Temp	Humid/ Condense	Radius	Combust Aerosols	Other Aerosols	Comb gases	Other gases
Probable level	Low	Low	Low	Medium or High	Low	Medium or Low	Low

Analysis of fire alarm cases

Date: 20/03/1991

Source: FAA INCIDENT DATA SYSTEM

Aircraft Make: LKHEED L-188-C

Carrier: REEVE ALEUTIAN AIRWAYS INC

Phase Flight: FCD/PREC LDG FROM CRUISE

Narrative: Dense fumes in cargo compartment. Diverted and landed. Smoke from box marked fish that contained batteries.

Probable environmental conditions at the time of event 3

Event 4: Description

Physical parameter	Temp	Humid/ Condense	Radius	Combust Aerosols	Other Aerosols	Comb gases	Other gases
Probable level	Low	Low	Low or Medium	Medium	Medium or High	Medium	Medium or High

Date: 05/09/1996

Source: NTSB AVIATION ACCIDENT/INCIDENT DATABASE

Aircraft Make: DOUG DC10-10F

Carrier: NOT REPORTED

Phase Flight: CRUISE

Narrative: The airplane was at fl 330 when the flight crew determined that there was smoke in the cabin cargo compartment. An emergency was declared and the flight diverted to Newburgh/Stewart international airport and landed. The airplane was destroyed by fire after landing.

The fire had burned for about 4 hours after smoke was first detected. Investigation revealed that the deepest and most severe heat and fire damage occurred in and around container which contained a DNA synthesizer containing flammable liquids. More of the structure was consumed than of any other container and it was the only container that exhibited severe floor damage. Further 6r was the only container to exhibit heat damage on its bottom surface and the area below container 6r showed the most extensive evidence of scorching of the composite flooring material. However there was insufficient reliable evidence to reach a conclusion as to where the fire originated. The presence of flammable chemicals in the DNA synthesizer was wholly unintended and unknown to the prepared of the package and shipper. The captain did not adequately manage his crew resources when he failed to call for checklists or to monitor and facilitate the accomplishment of required checklist items.

The department of transportation hazardous materials regulations do not adequately address the need for hazardous materials information on file at a carrier to be quickly retrievable in a format useful to emergency responders. Probable environmental conditions at the time of event 4

Summary

The exploitation of actual fire alarm events is tricky because most of the time, the parameters recorded at the time of the event do not allow to determine the condition for which the alarms were triggered and can even lead to wrong conclusions. However this analysis has allowed us to clarify some typical fire and non−fire situations and to outline performance tests accordingly.

Fire sources are extremely diversified and, in particular the materials involved are most of the time unexpected or even normally forbidden as cargo loads. As well their combustion products or effects are variable with, according to the event, predominance of different physical parameters. False alarm sources are also diversified, in some cases the corresponding single physical parameters are very close to those characteristics the start of a fire.

Under these conditions, the adjunction of several detection criterion can increase considerably the discriminatory capabilities of the fire detection systems. The dynamic of the various signals has to be taken into account in the fire alarm decision as an additional discriminatory factor, for this a minimum analysis duration is necessary which is very often not compatible with the current certification criteria (considering in particular the propagation time of the combustion products). Performance development or qualification tests must be on one hand feasible under well control metrological conditions and on the other hand representative of a large range of realistic fire and non − fire situations.

References

[1] Schmoetzer, K . Aircraft Fire Detection: Requirements, Qualification and Certification Aspects, see this book of conference.

[2] FAA In service events Data Base.

[3] NTSB In service events Data Base.

[4] Blake, D. FAA Technical Center, Fire Safety Section, Report No DOT/FAA/AR-TN0029, June 2000.

[5] EN 54-9 Components of automatic fire detection systems Part 9 Methods of test of sensitivity to fire“.

Appendix B

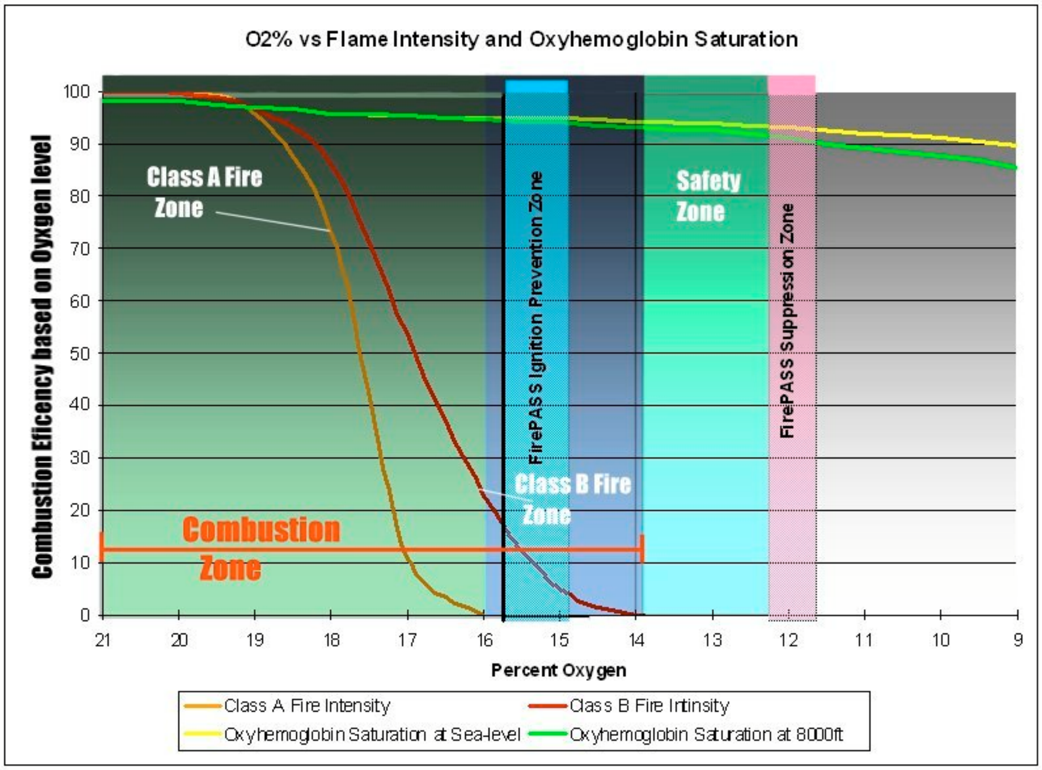
Definition of the Pas Quill Stability Classes

The amount of turbulence in the ambient air has a major effect upon the rise and dispersion of air pollutant plumes. The amount of turbulence can be categorized into defined increments or ″stability classes″.

The most commonly used categories are the Pas quill stability classes A, B, C, D, E, and F. Class A denotes the most is unstable or most turbulent conditions and Class F Denote the most stable or least turbulent conditions.

Enclosure Fire Dynamics

"Oxygen saturation at altitude versus Hypoxic air in combustion." Why do two environments which contain identical partial pressures of oxygen (i.e. the same number of oxygen molecules per specific volume) affect the processes of ignition and conduction so different The answer is simple: "The difference in oxygen concentration in these two environments diminishes the availability of oxygen to support combustion. This happens due to the increased number of nitrogen molecules interfering with the kinetic properties of oxygen molecules". In other words, the increased density of nitrogen molecules in the environment creates a "buffer zone" that obstructs the availability of oxygen radical for combustion. When the kinetic properties of both gases are compared it is revealed that nitrogen molecules are both slower and have a lower penetration rate (by a factor of 2.5) than oxygen molecules.



Appendix Figure B1 The Difference in Oxygen Concentration v/s Flame Intensity
Source: Navy/Civil Ailine fire test, international aero Inc.

International Aero Inc. participated in the latest Navy / Civil airliner fire test series, conducted at the Memphis Group in Greenwood Mississippi. This series were sponsored by the Richard Healing, Director Navy Safety and Survivability, the test was supported by AWIGG members.

These tests prove the viability of using potable water and nitrogen or air to suppress fires caused by terrorist acts in the cabin. Fires were extinguished, even in non- accessible areas using Low Pressure Dual Fluid water mist.

This new evolving technology will prove, in the future, to be the best and most affordable method of protecting the traveling public. The IAI approach to a total system using existing resources available on the aircraft will be the future of fire protection in the pressurized cabin of commercial airliners. Flight test were flown in August 2001. This cutting edge safety system proved to be the next generation of fire suppression systems. Risk benefit reports are in, we were right. (Source; Industrial Fire Hazard Protection)

Risk Assessment

What is Risk?
What is Risk Assessment?
What are the Goals of Risk Assessment?
What is the Procedure for Performing a Risk Assessment?
How Do I Estimate Risk?
What is the Point of Doing a Risk Assessment?
What is Risk Management?
How Do You Combine Risk Assessment with Risk Management?

What is Risk?

A common definition of risk is that it is the combination of a specific hazard and the likelihood that the hazard occurs **(probability) x (hazard) = risk.** That likelihood may be expressed as a rate or a probability. For example the risk of an aircraft accident (hazard) can be expressed as one accident per million flights (likelihood).

Risk can be objectively defined so that two people can take the same data and come up with a similar result. Risk can be expressed in many ways, so long as it combines a hazard with a likely hood. The concept of risk exists in aviation, finance, human health, and many other areas. One can use the methods of science, engineering, and math in order to define risks.

Risk Assessment

The process of analyzing a potential losses from a given hazard using a combination of known information about the situation, knowledge about the underlying process, and judgment about the information that is not known or well understood.

Risk is defined as the product of a hazard (such as damage costs) and the probability that this hazard occurs. In other words, **(probability)x(hazard) = risk.** The first two values must be known or at least estimated in order to define risk.

<u>The Goals of Risk Assessment.</u>

The basic goals of risk assessment include the following:

- Identify potentially hazardous situations,
- Apply appropriate methods to estimate the likelihood that a hazard occurs, and the uncertainty in that estimate,
- Provide alternative solutions to reduce the risk,
- Estimate the effectiveness of those solutions,
- Provide information to base a risk management decision, and

Estimate the uncertainty associated with the analysis.

<u>How to Estimate Risk</u>

Estimating risk can be done in several ways:

- With historical data,
- By modeling,
- By breaking down the system into known subsystems using techniques such as event trees or fault trees,
- By analogy with similar situations,
- By comparison with similar activities, or
- By using a combination of methods.

<u>How to Combine Risk Assessment with Risk Management.</u>

The combined risk assessment and risk management process can be described as a six step process. The first three steps are associated with risk assessment and the last three with risk management.

1. Formulate problem in a broad context - Do this by answering questions like: What is the problem?, Who must manage the problem?, Who are the stakeholders? Also, establish relationships among the problems and rely on stakeholders for problem identification and characterization.

2. Perform the risk analysis - Evaluate the risk in order to determine the hazard, the likelihood of the hazard occurring, and any uncertainties in the estimate

3. Define the options - Determine what can be done about the risk issue and the ways that it could be done. Determine potential consequences, costs, and benefits.

4. Make sound decisions - Determine the best solutions and how they could be implemented in ways that are feasible, cost effective, and socially acceptable.

5. Implement decisions - Find out what actions are needed to implement and deal with any objections or reassessments.

Source : Risk Assessment Basics, AirSafe.com, LLC,
(http://airsafe.com/risk/basics.htm --)
Revised: 7 February 2003

Minimum Performance Standard for Aircraft Cargo Compartment.

Federal Aviation Regulations (FARs) and Joint Airworthiness Requirements (JARs) require fire suppression systems for some classifications of cargo compartments. In the past, the aircraft industry selected HALON 1301 total flood fire suppression systems as the most effective means for complying with the regulations. Because of the ban on production of HALON 1301 (effective January 1994, as mandated by the Montreal Protocol), new fire suppression systems will need to be certified when HALON 1301 is no longer available. The tests described in this standard are one part of the total Federal Aviation Administration (FAA) and the Joint Aviation Authority (JAA) certification process for cargo compartment fire suppression systems.

Appendix Table B1 Hypoxic Atmosphere Testing

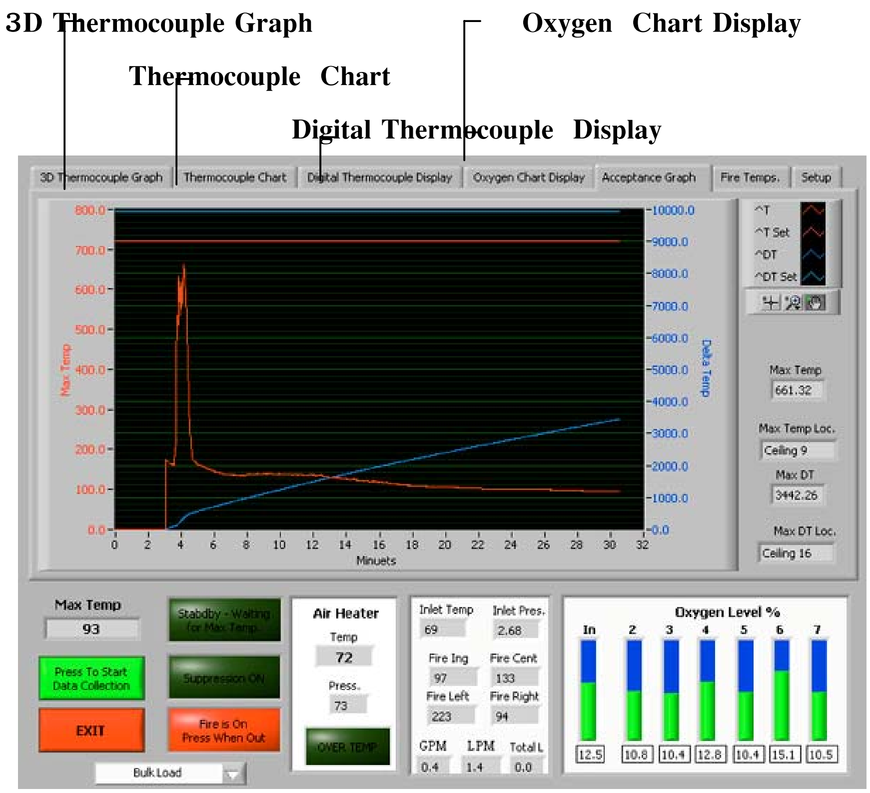
Date	Cargo MVPs Requirement	Temperature	Oxygen levels in the device	
Oct.14	Bulk load MPS	Temp	Hypoxic Atmosphere	Photos
Oct.14	Bulk load MPS with water additive	Temp	Hypoxic Atmosphere	Photos
Oct.13	Bulk Load MPS	Temp	Hypoxic Atmosphere	
Oct.13	Bulk load MPS with water additive **	Temp	Hypoxic Atmosphere	
Oct. 10	Bulk load MPS	Temp	bulk load Hypoxic Atmosphere	
Oct. 08	Surface load MPS	Surface Temps	Surface load Atmosphere	
Oct. 09	Bulk load MPS	Temp	Hypoxic Atmosphere	
Oct. 03	1st Bulk Load fire test	Temps	Hypoxic Atmosphere	
Oct. 22	Container Load MPS	Container Temp	Hypoxic Atmosphere	
Oct. 23	Container Load MPS	Container Temp	Hypoxic Atmosphere	Photos
Oct. 27	Container Load MPS	Container Temp	Hypoxic Atmosphere	
	Fire PASS Hypoxic Air Preventive Mode data below			
13 Nov	180 Minute ETOPS Preventive mode	Data stream	Photo results link to the right	Photos
30 Oct	Preventive mode Part A	Preventive mode Part B	Hypoxic plot	Photos
31 Oct	Stable no fire temp plot	Temp at T+90	Hypoxic plots A B	Photos

Oct.14/bulk load MPS

Source: http://pyrogen.com down load 2004

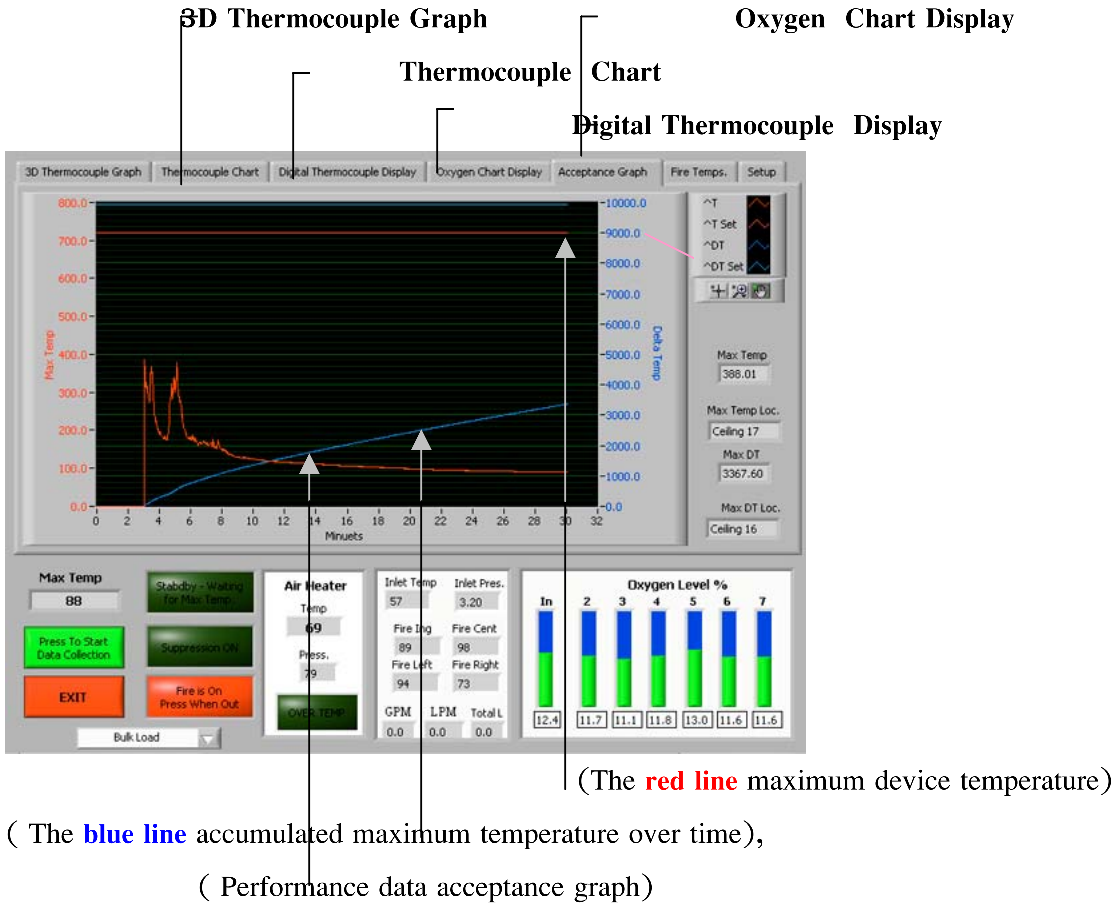
IAT Fire Lab and Fire PASS developed the first "Gate to Gate" fire Suppression system for commercial airliners.

In the Minimum Performance Standard data screen below the **red line** (maximum device temperature) and the **blue line** (accumulated maximum temperature over time), can not cross the HALON 1301 level of safety (upper flat matching color lines). If the data does not exceed the level of safety demonstrated with HALON the alternative agent passes.



Appendix Figure B2 Minimum Performance Standard data
(Oct.13/bulk load MPS with water additive**)

Source: http://pyrogen.com, down load 2004



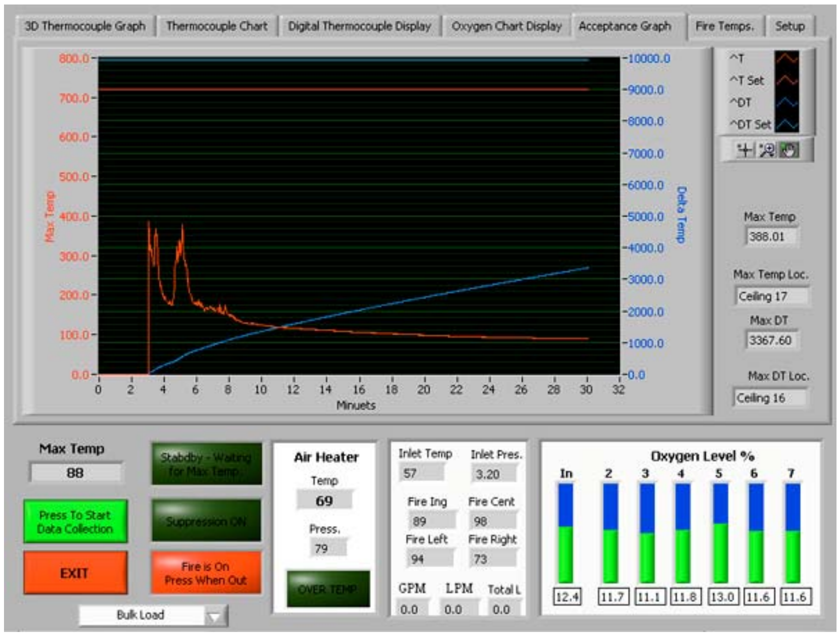
Appendix Figure B3 Minimum Performance Standard Data

Source: http://pyrogen.com, down load 2004)

The test MPS was developed in conjunction with the International Aircraft Fire Protection Systems Working Group (IAFPSWG), over the last five years. In the below chart the systems passed the FAA requirements. To date every test has been better than HALON 1301. Temperature column shows values 1″ below the ceiling and along the side walls of the device. Oxygen column shows O_2 concentrations at 5 locations inside the device and the input.

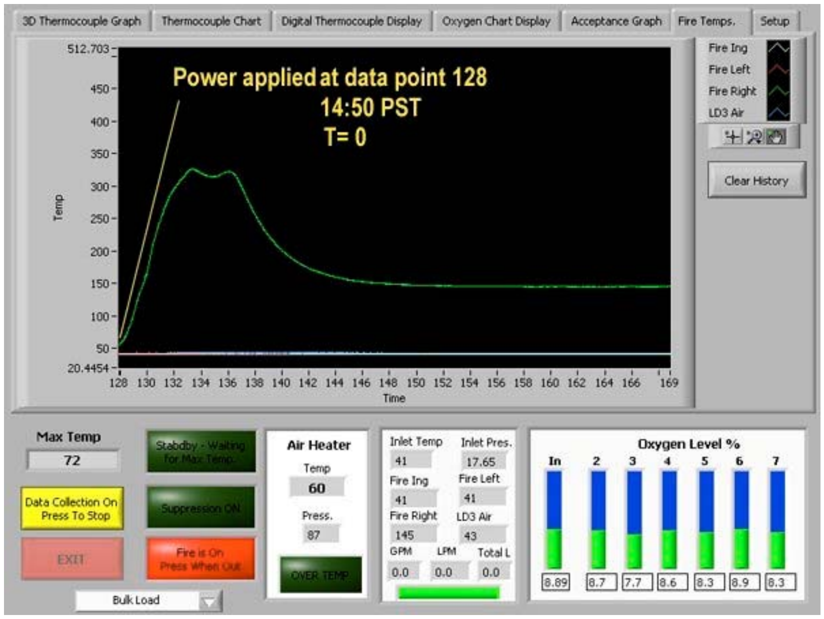
- Mister pressure on the below test was at 2.86 psi (two and three quarter pounds).
- The Low Pressure Dual Fluid misting nozzle was developed by NAVAIR in the mid 90's.
- It has been used on several full scale aircraft and flight test.

- One big advantage if the nozzle is it will not clog, and it performs well from 2 through 100 psi. Mixing the water and Hypoxic conditioning air and variable pressures and still obtaining the same size water droplet.



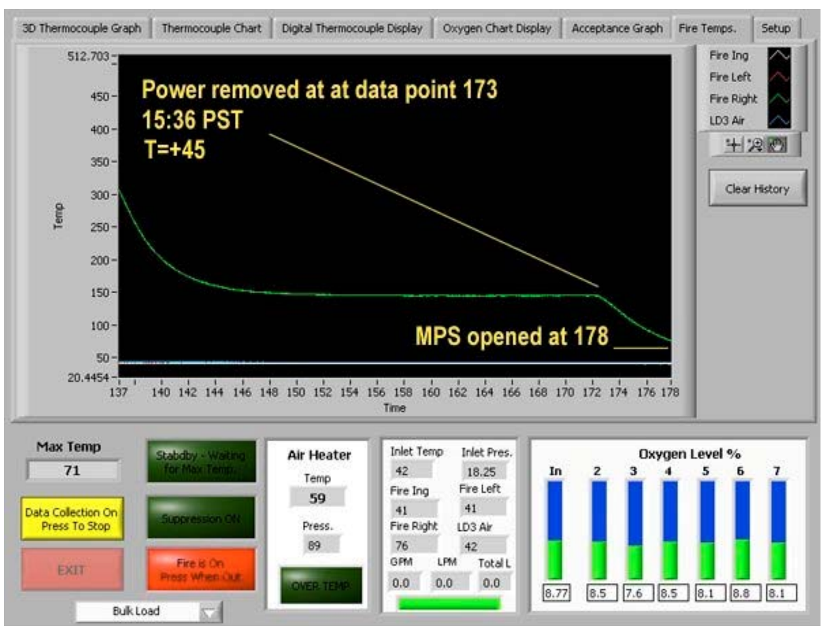
Appendix Figure B4 Oct.14/bulk load MPS with water additive**
Source: http://pyrogen.com, down load 2004

Water enhance were also successfully tested. It is felt that they will help prevent flame spread and help wet the area as the O_2 levels are reduced. The mister is capable of dispensing the water horizontally up to 7 meters at one bar pressure. The best part is everything is already on the aircraft, air-conditioning, water, Inertial system membranes, Its too easy. Check back for more details and test data.



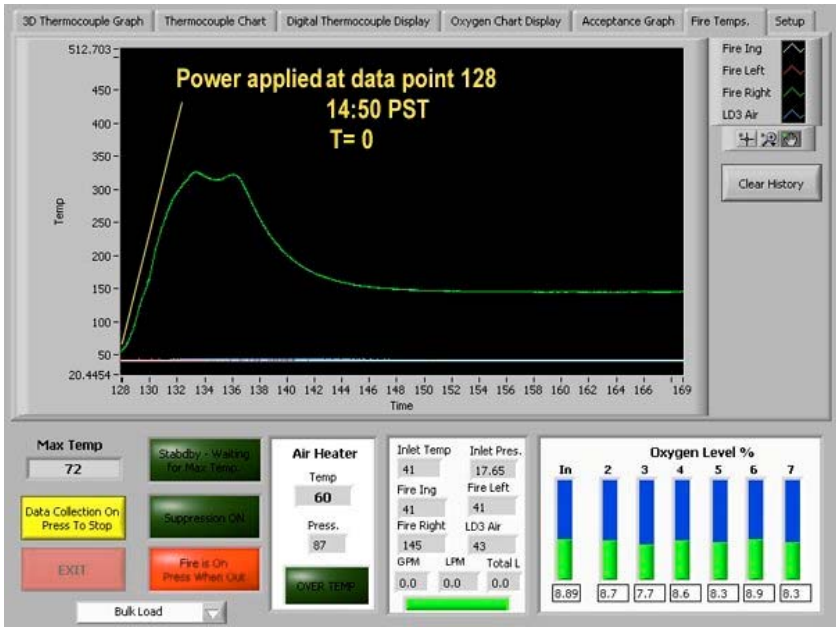
Appendix Figure B5 Preventive Mode Part A Stable no Fire Temp Plot

Source: http://pyrogen.com, down load 2004

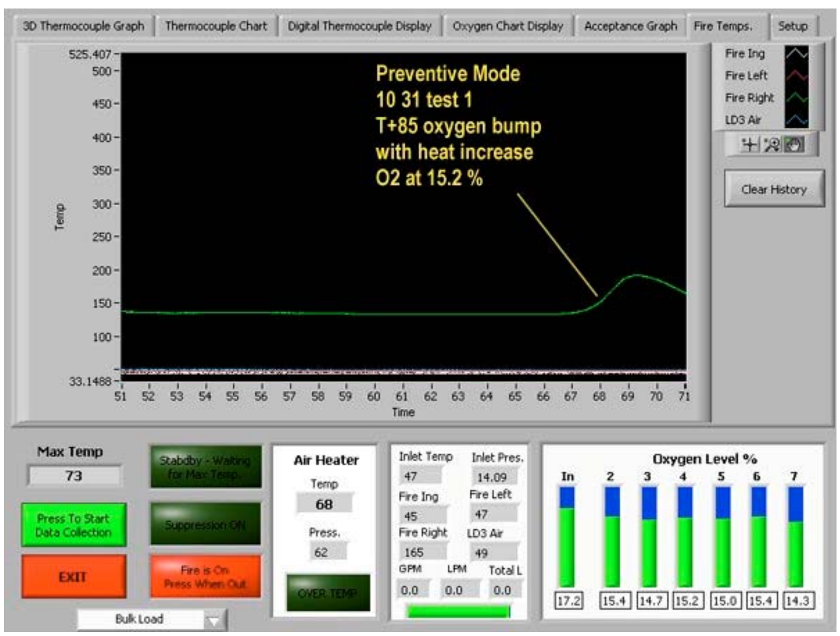


Appendix Figure B6 Preventive mode Part B (Oct.31/Stable no fire temp plot)

Source: http://pyrogen.com, down load 2004



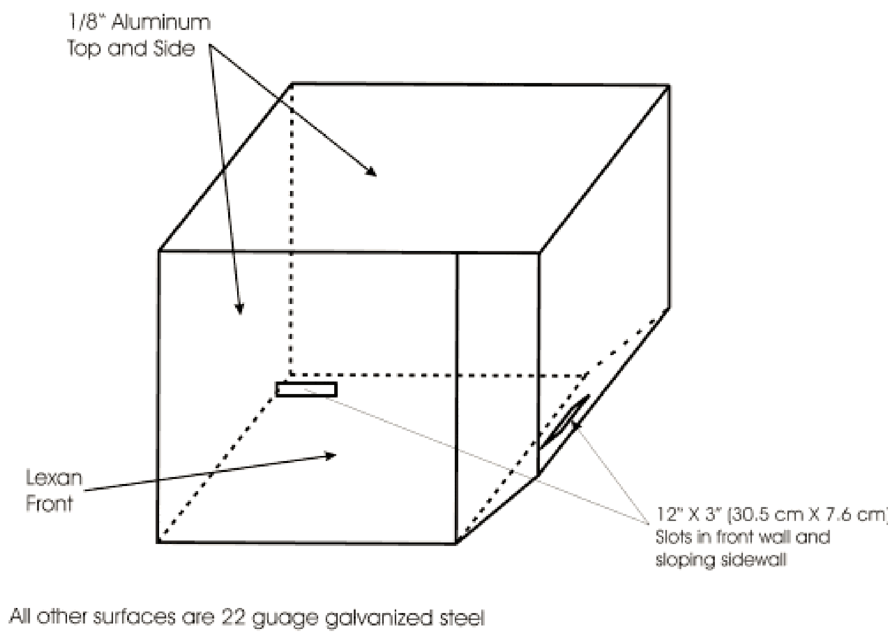
Appendix Figure B7 Preventive Mode Power Applied with Low Oxygen Level %



Appendix Figure B8 Stable No Fire Temp Plot Temp at T+85

FAA orders airlines to install new fuel tank inertial system to reduce chance of explosion a cost-benefit analysis still must be done and airlines need time to plan for the change, so the requirement is not expected to take effect for at least two years. Once the rule is issued, the so-called fuel-tank inerting program will be phased in over seven years. During that time existing planes will have to be retrofitted with the device and new planes will have them as standard equipment.

The Cargo Pit is next, this system is 90% of what is required for the cargo system, WE are one valve away water mist and Hypoxic Air Suppression test



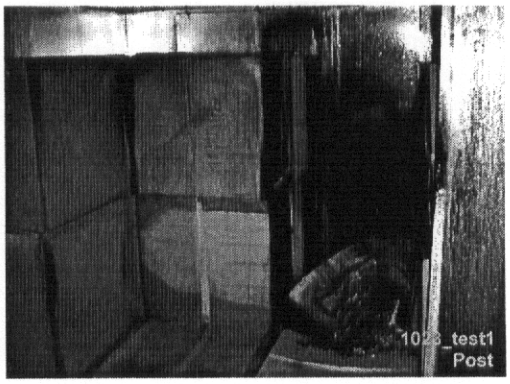
<u>Appendix Figure B9</u> The2000 Cu-Ft. Representation of a Wide Body Cargo Bay. LD3 Containers are Placed in One Corner.

Source: Pyrogen Aerosol Technology Fire Protection (http://www.pyrogen.com)

Appendix Figure B10 Post Fire Test in LD3 Containers are Placed in One Corner Removed Revealing Damage

Source: Pyrogen Aerosol Technology Fire protection (http://www.pyrogen.com)

Row 2 outside boxes removed. Note the row one boxes are still intact. Row 2 center and top boxed have fallen into the fire during the test. They blocked in inlet slit and forced the mist into the igniter and right lower box. This is probably due to thermal currents created by the fire. This prevented the fire from spreading to the Row 3



Appendix Figure B11 Post Fire Test in LD3 Containers Removed Revealing Damage

Note: no damage to row three and four. Although these show some heat discolor and smoke stains there is no char

Source: Pyrogen Aerosol Technology Fire Protection (http://www.pyrogen.com)

The Definition of The Pas quill Stability Classes:

The amount of turbulence in the ambient air has a major effect upon the rise and dispersion of air pollutant plumes. The amount of turbulence can be categorized into defined increments or ″stability classes″.

The most commonly used categories are the Pas quill stability classes A, B, C, D, E, and F. Class A denotes the most unstable or most turbulent conditions and Class F denotes the most stable or least turbulent conditions. The definition of the Pas quill Stability Classes: The amount of turbulence in the ambient air has a major effect upon the rise and dispersion of air pollutant plumes. The amount of turbulence can be categorized into defined increments or ″stability classes″.

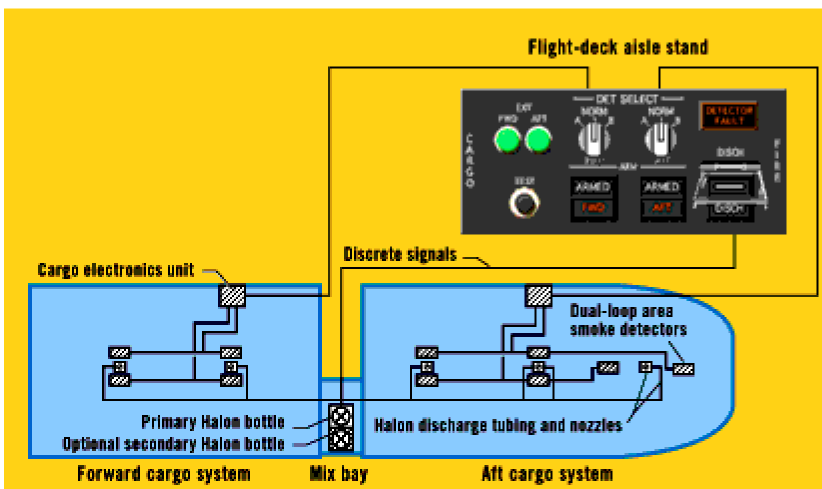
The most commonly used categories are the Pas quill stability classes A, B, C,D, E, and F. Class A denotes the most unstable or most turbulent conditions and Class F denotes the most stable or least turbulent conditions.

Appendix C

Retrofit

Boeing began installing smoke-detection and fire-suppression systems into 737 production airplanes at line position 3078 for the 737-300/-400/-500 models and at line position 91 for 737-600/ -700/-800 models. The production deliveries also include 195-min ETOPS configurations. (The 195 min allows for 180-min ETOPS diversion followed by 15 min for missed approach and emergency passenger evacuation.)

To support operators in retrofitting their airplanes, Boeing has developed modification kits, including revised documentation and the respective service bulletins. The Boeing portion of the kits will include all hardware for installing the detection and suppression systems, including suppression tubes, wire bundles, support brackets, detector pans, suppression pans and nozzles, and all standard-type hardware. An additional buyer-furnished equipment (BFE) hardware kit will also be required. The retrofit system uses the same components as the production system.



Appendix Figure C1 Dual-Loop Photoelectric System Schematic
Source: Boeing modification kits (http://www.airlinesafety.com/faq/faq9.htm)

The retrofit 737-300/-400/-500 service bulletin package will include multiple configurations, including auxiliary fuel cell‑configured and ETOPS-equipped airplanes. Auxiliary fuel cell configurations include aft cargo compartment single Boeing fuel cells, single Rogerson fuel cells, and dual Rogerson fuel cells. These unique configurations will be identified as separate groups within the service bulletin. ETOPS-equipped airplanes will have a second 33-lb Halon bottle installed on the opposite side of the mix bay.

Boeing has identified five different suppliers for the BFE kits and has qualified hardware from each supplier. Four suppliers have been qualified to provide smoke detectors (fig. 59) for Boeing-designed airplanes. All four detectors are considered interchangeable and intermixable. Additionally, Boeing has qualified two HALON bottle sources. The cargo electronics units and flight-deck control panel are considered single-source items. Boeing suggests that operators contact individual manufacturers for BFE kits.

To ensure that the Boeing-supplied and BFE kits meet installation requirements, Boeing has completed service bulletin validations on the 737-200/-300/-400/ -500. The 727-200 validation is expected to be completed in early 1999. The company is in the process of determining the method of validation when the 737-600/ -700/-800 bulletins become available.

Appendix Figure C2 Approved-Type Smoke Detectors
Source: Boeing modification kits (http://www.airlinesafety.com/faq/faq9.htm)

Boeing has developed a comprehensive plan to assist operators in meeting a new FAA rule to convert Class D cargo compartments to Class C or Class E compartments. To help operators comply with the March 18, 2001, deadline to install smoke-detection systems, fire-suppression systems, or both in existing Class D compartments, Boeing has completed the necessary steps to support the in-service fleet of Boeing-designed commercial airplanes. Those steps include the certification efforts, system design, service bulletin validations, and kit development to make Class D compartments compliant with Class C or Class E specifications.

A bottle in the air-conditioning mix bay between the forward and aft cargo compartments contains HALON 1301. The HALON bottle can discharge to either compartment, but once activated, the system cannot be reversed to the other compartment. A sensor detects HALON bottle pressure and activates the HALON low-pressure indicator on the flight deck when the bottle discharges or loses pressure.

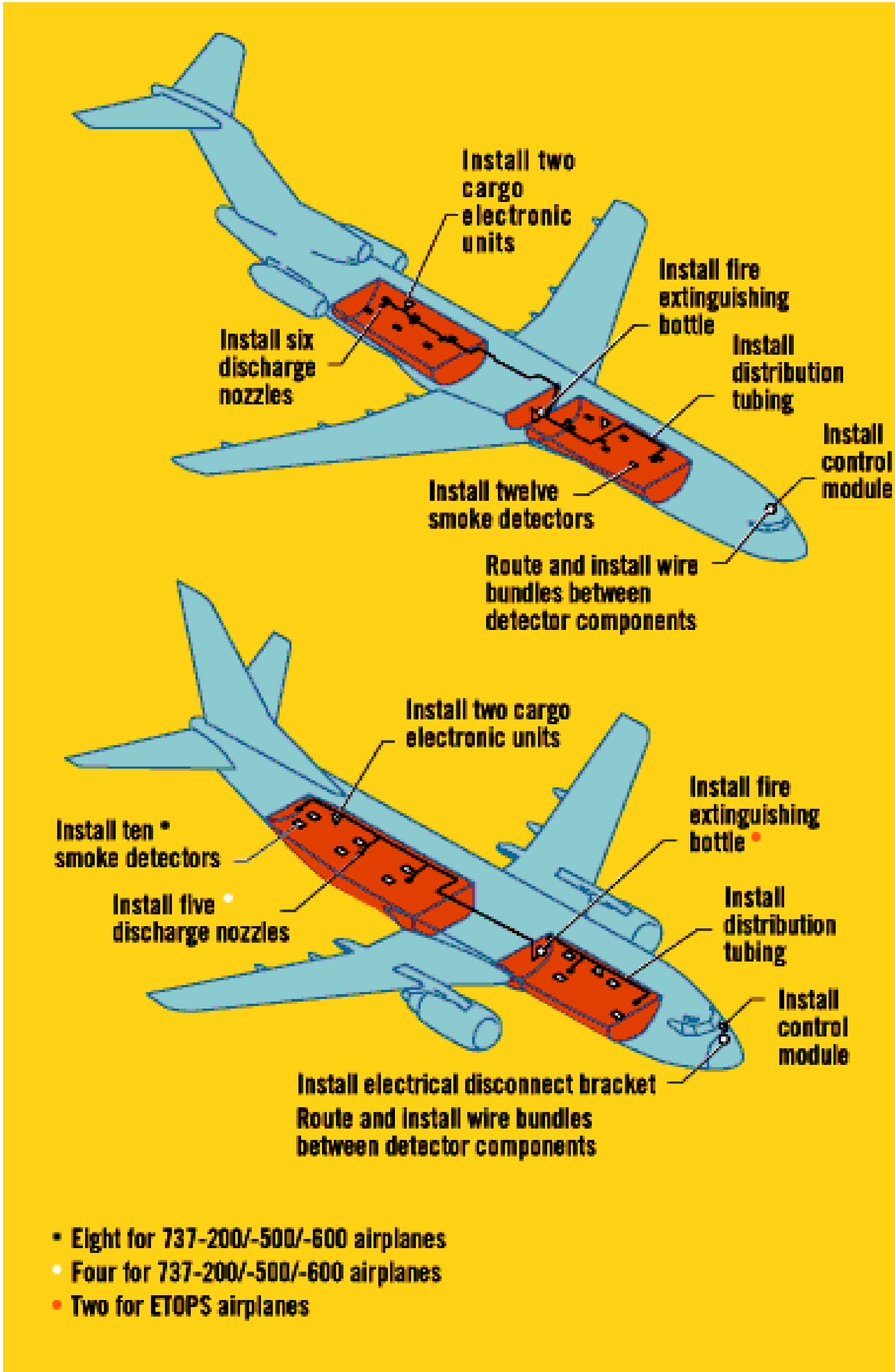
The TEST switch checks the condition of the discharge nozzles in both compartments. The FWD and AFT indicators illuminate green when the system is functioning normally. Airplanes may not be dispatched with a loaded cargo compartment if the fire-suppression system exhibits any faults.

Smoke Detection; Current specifications for Class C compartments require that the smoke-detection system alert the flight crew within 60 sec from the time smoke first appears in the compartment.

Fire suppression; Current specifications for the fire- suppression system in each Class C compartment require a minimum initial concentration of 5 percent HALON throughout the compartment to suppress any combustion to controllable levels. Thereafter, the system must sustain a minimum concentration of 3 percent HALON for 60 min to prevent re-ignition or spreading of the combustion. For airplanes certified for extended-range twin-engine operations (ETOPS), the fire-suppression system must be able to sustain a 3 percent concentration of HALON within the compartment for a maximum of 180 min.

Cargo Compartments Class

Boeing has developed a comprehensive plan to assist operators in meeting a new FAA rule to convert Class D cargo compartments to Class C or Class E compartments. To help operators comply with the March 18, 2001, deadline to install smoke-detection systems, fire-suppression systems, or both in existing Class D compartments, Boeing has completed the necessary steps to support the in-service fleet of Boeing-designed commercial airplanes. Those steps include the certification efforts, system design, service bulletin validations, and kit development to make Class D compartments compliant with Class C or Class E specifications



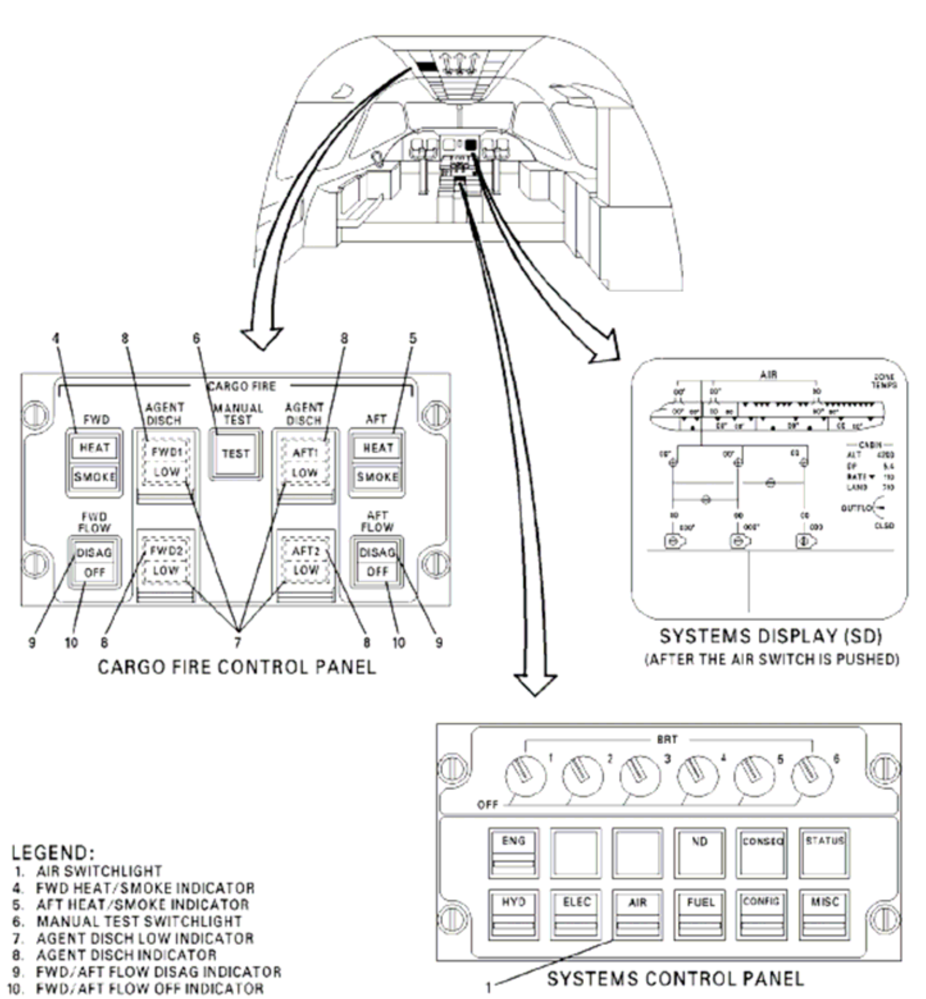
<u>**Appendix Figure C3**</u> B727, B737-Retrofit

Source: Boeing modification kits (http://www.airlinesafety.com/faq/faq9.htm)

Appendix D

System Operation

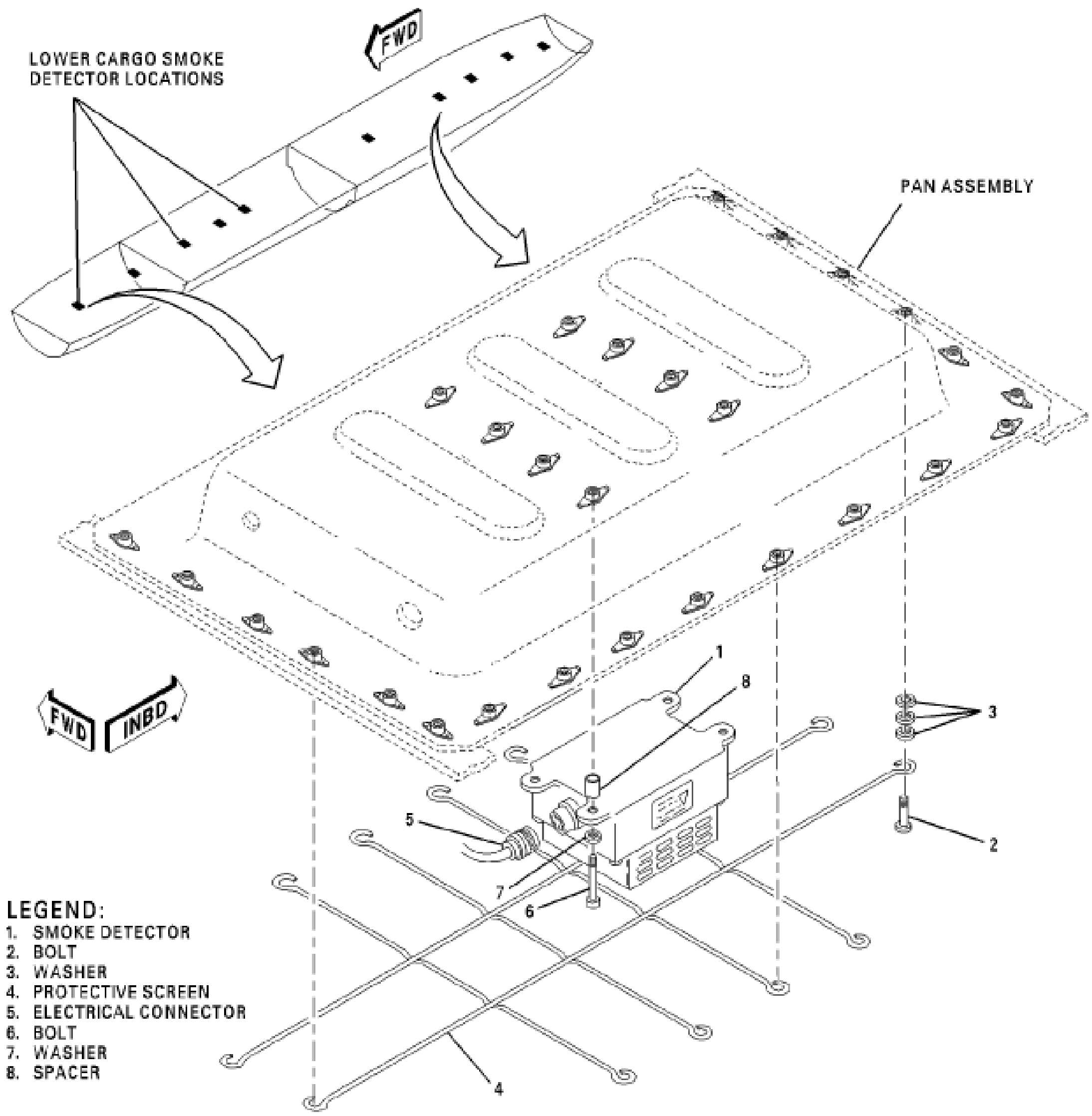
A. When smoke goes through the detector, it causes a reflection of the light from the LED to the photocell. This reflection increases the output voltage of the photocell. When this occurs, the logic circuit in the smoke detector compares the photocell voltage to a reference voltage. When the photocell voltage is more than the reference voltage, an alarm circuit is activated.



Appendix Figure D1 Cargo Fire Detection Indications - Flight Compartment

Source: MD-11 AIRCRAFT MAINTENANCE MANUAL Figure 2/26-14-00-990-827

B. When the temperature in the forward or center/aft lower cargo compartment gets to the set value (1908F [105.58C]), the overheat detector switch closes. This causes the HEAT of the applicable red HEAT/SMOKE light on the cargo fire panel to come on. It sends a signal to the DEU and the MSC. Heating and ventilation are stopped as long as the heat condition exists.



Appendix Figure D2 Lower Cargo Smoke Detector - Removal/Installation

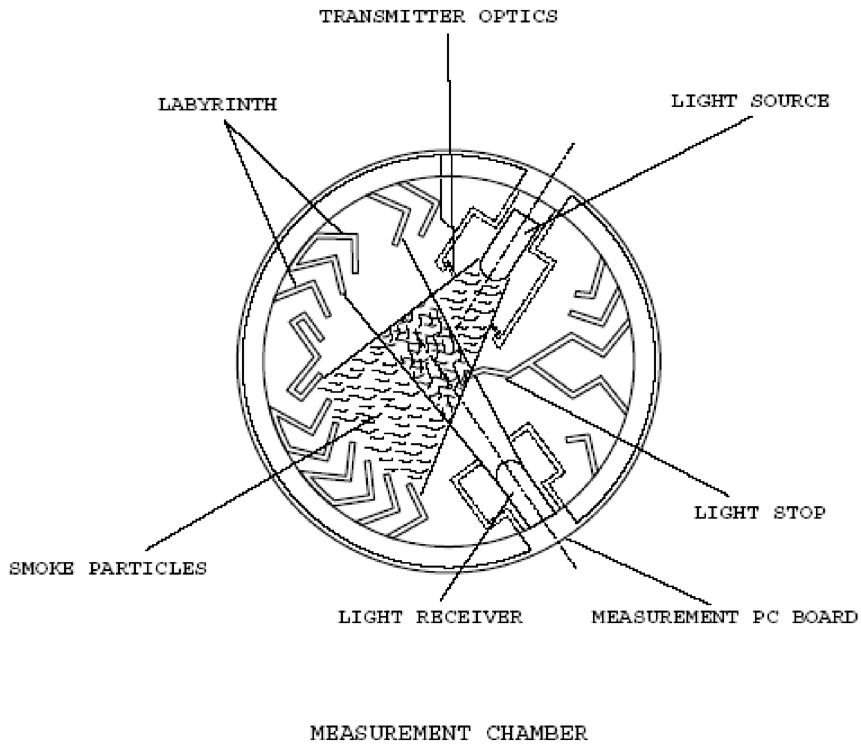
Source: MD-11AIRCRAFT MAINTENANCE MANUAL Figure 401/26-14-01-990-801

Optical smoke detector operation

The optical measurement chamber detector (Figure D3) permits to detect light colored and dark smoke particles. The smoke detection is based on the scattered light principle. The light source, the light stop and the light receiver are arranged in such way the light from the emitter cannot directly reach the receiver. When smoke particles are present in the optical path (from light source), some scattered light reach the light receiver (Figure D4) and produce an electric signal. The labyrinth permits the light trap to be efficient and insensitive to false alarms such as parasite light.

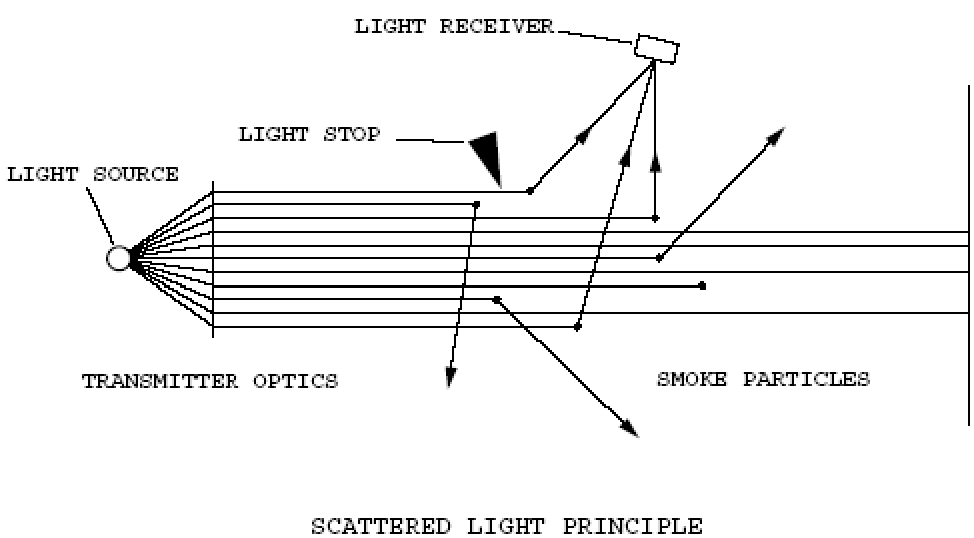
Cigarette smoke with optical smoke detector, in the case of OSD. The diameter of particles is not increased by the pressure of icons as with ionic detectors. It is most important that smoke particles reflect the light received from the emitting light. Cigarette smoke is a white smoke, consequently it reflects more easily the red light.

Brief light pulses ($\approx$ 100 µS) are transmitted periodically by the light source (IR_LED) into the scattering chamber (Figure D5). The wavelength of the light is typically 880 nm (near infrared) in order to optimize the detection efficiency. Finally the light receiver (photo diode) receives any scattered light and converts it into an electrical signal, to be processed by the electronics.



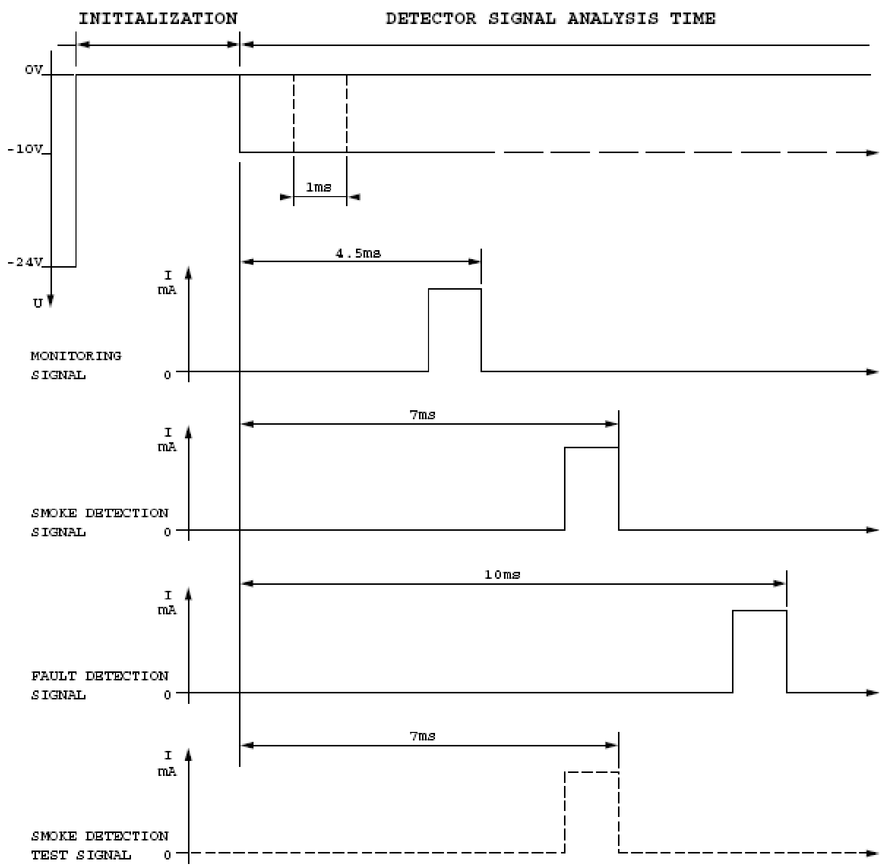
Appendix Figure D3 Optical Measurement Chamber Detector, OSD

Source: Airbus Service Information Letter no. 26-030, 2003



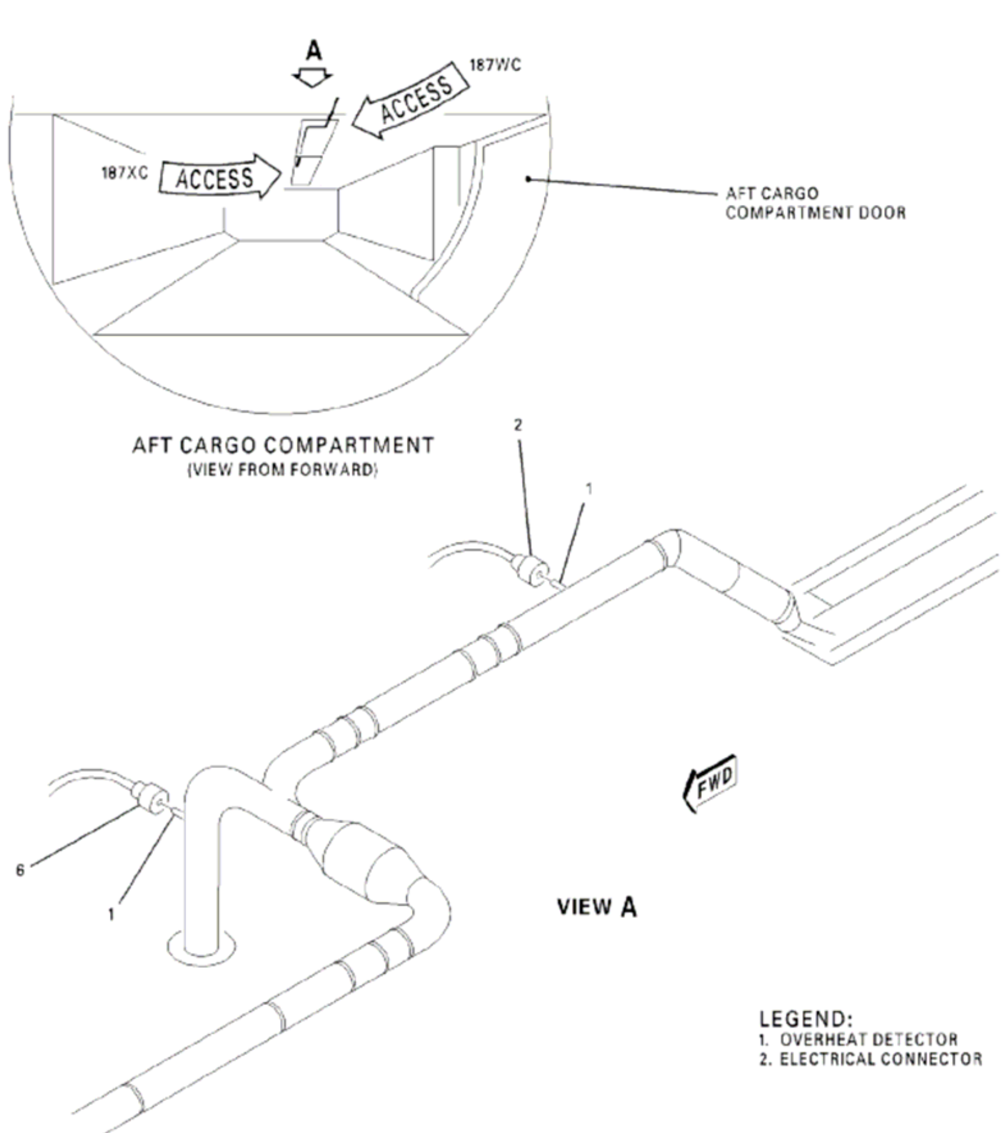
Appendix Figure D4 Principle of Optical Smoke Detector Measurement Chamber Descriptions and Operating.

Source: Airbus Service Information Letter no. 26-030, 2003



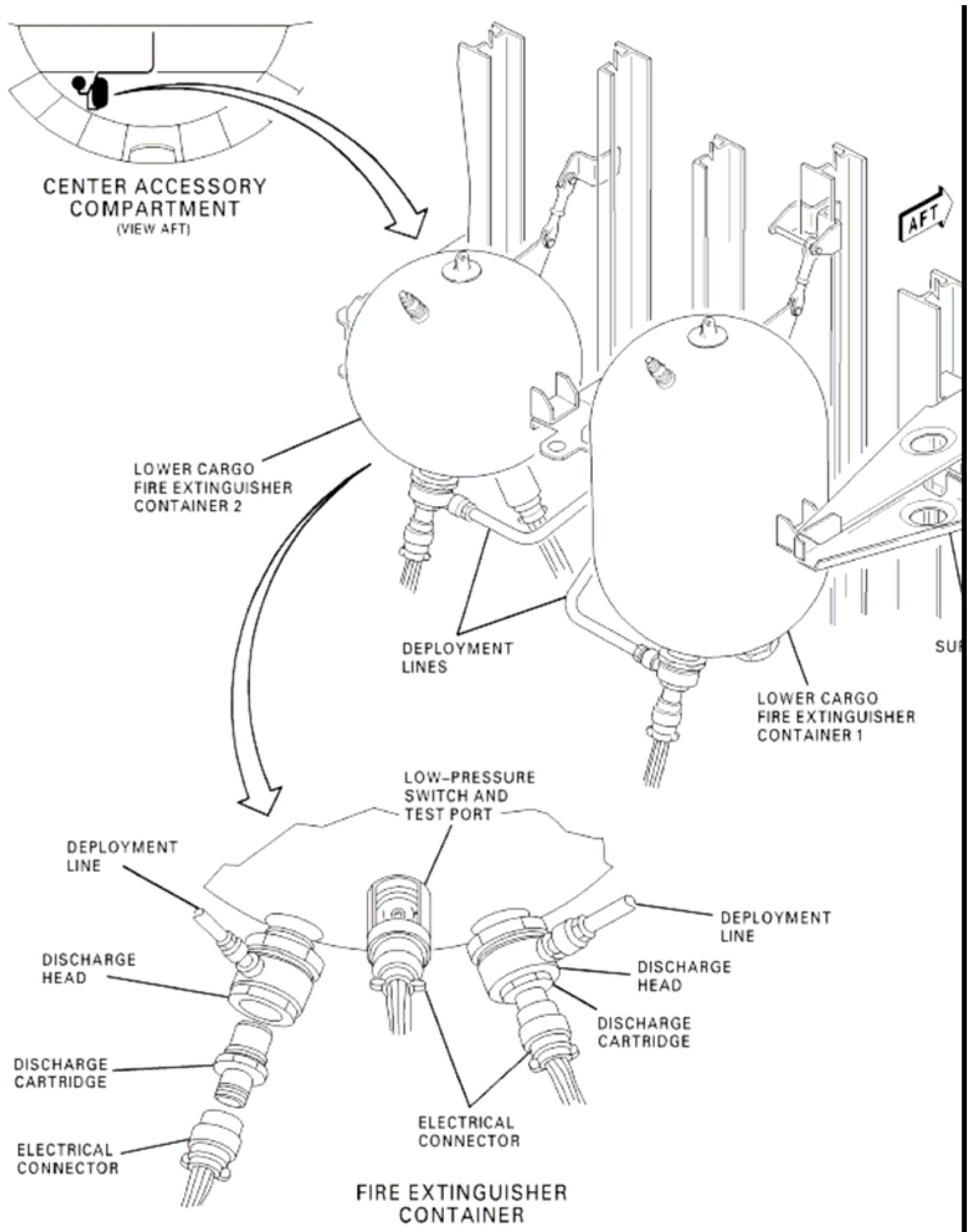
Appendix Figure D5 Detector Response Pulse Signal Analysis.
Source: Airbus Service Information Letter no. 26-030, 2003

The following appendix figures are retrieved from source of MD-11 Aircraft FIM Manual chapter 26 - 15 – 00 and MD-11 AIRCRAFT SIMPLIFIED SCHEMATIC 26 - 15 - 00 (called ATA –Chapter), chapter 26 is contained the fire protection subject and follow sub chapter means more content details which is explained and distributed into sub subjects.



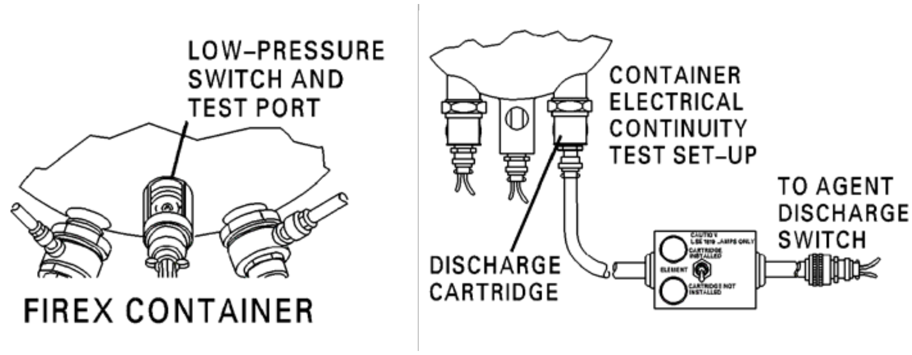
Appendix Figure D6 Aft Lower Cargo compartment & Overheat Detector Removal/Installation

Source: MD-11 AIRCRAFT MAINTENANCE MANUAL Figure 403/26-14-02-990-802



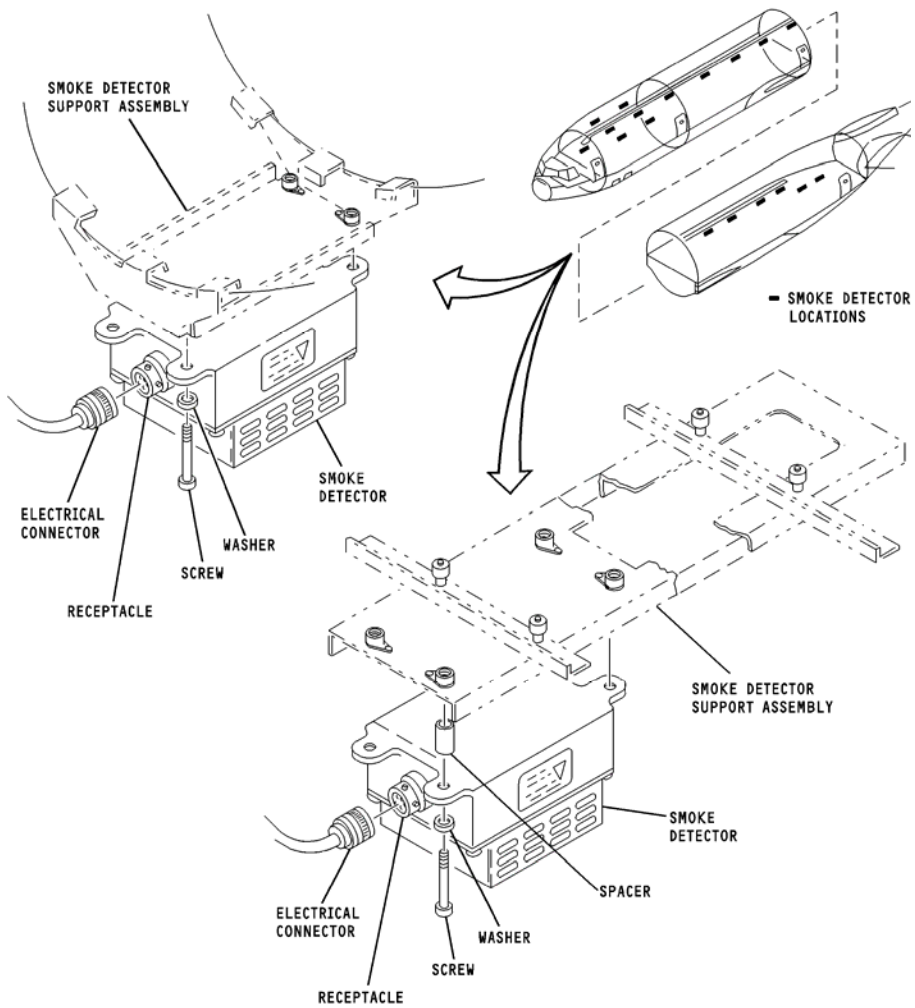
Appendix Figure D7 Lower Cargo Compartment Fire Extinguisher Containers and Control Discharge Switches.

Source: MD-11 AIRCRAFT MAINTENANCE MANUAL Figure 403/26-14-02-990-802



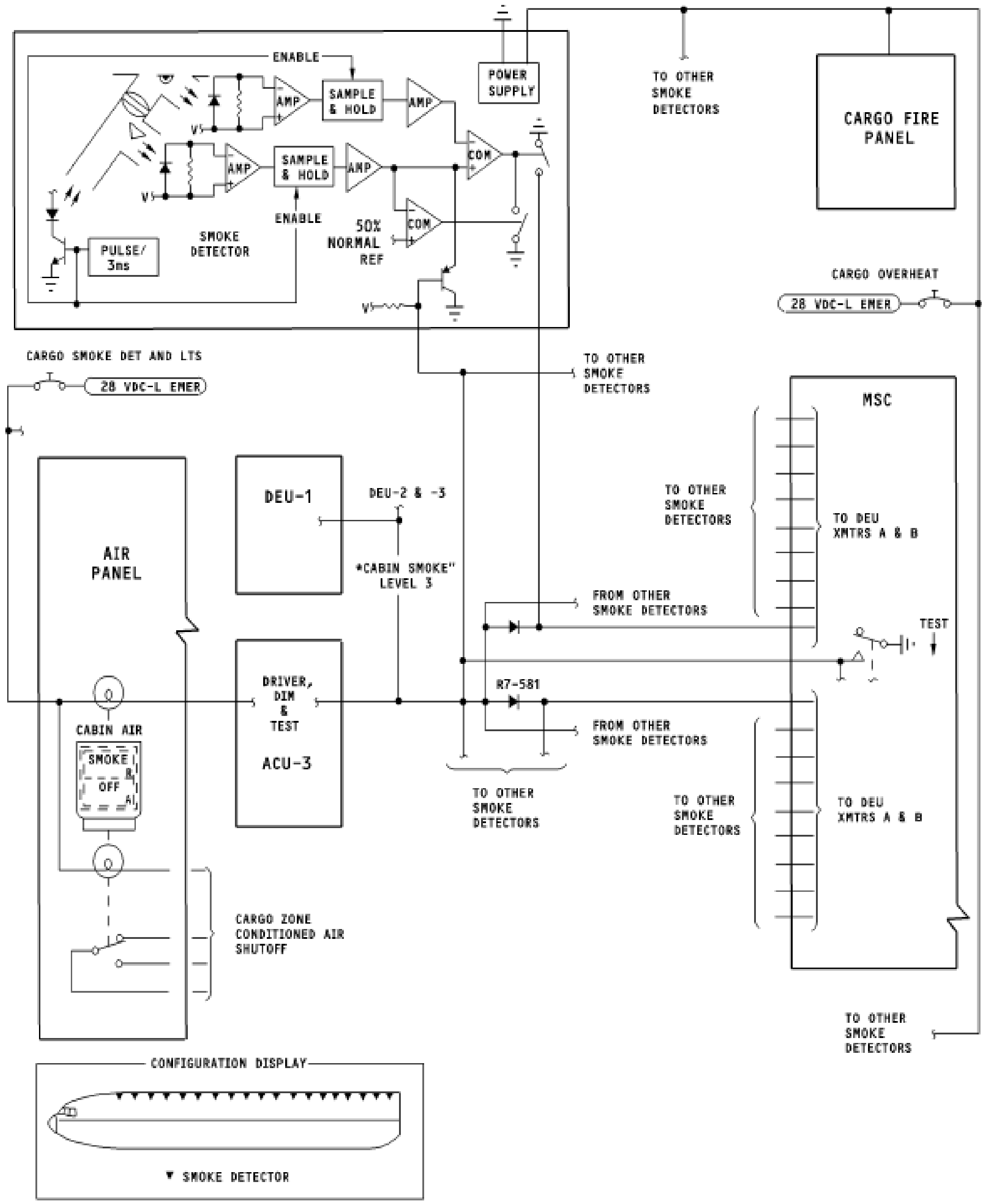
Appendix Figure D8 Lower Cargo Compartment Fire Extinguishing

Source: MD-11 AIRCRAFT MAINTENANCE MANUAL Figure 403/26-14-02-990-802



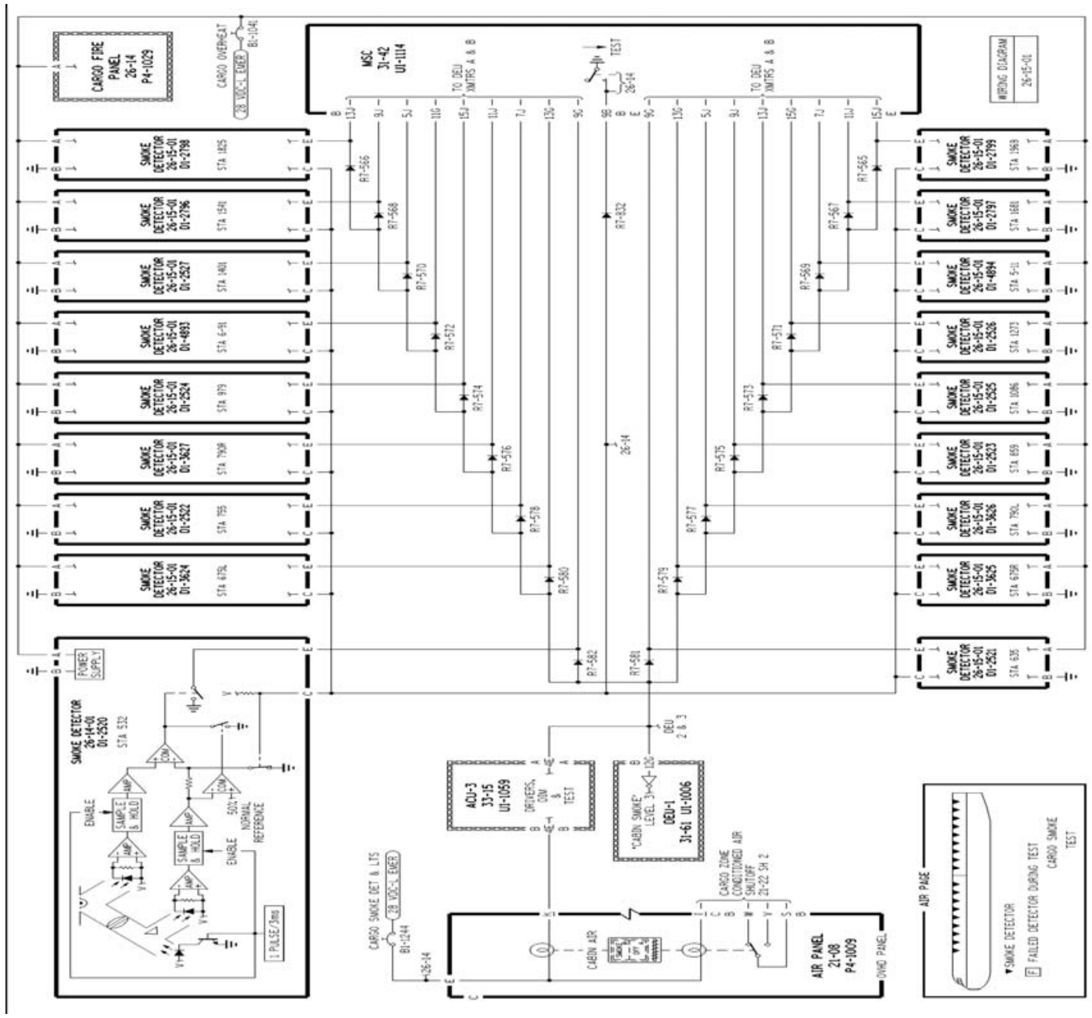
Appendix Figure D9 Cargo Fire Detection, Detectors Location.

Source: MD-11 AIRCRAFT FIM MANUAL 26 - 15 - 00 Page 103 Jul 1/01

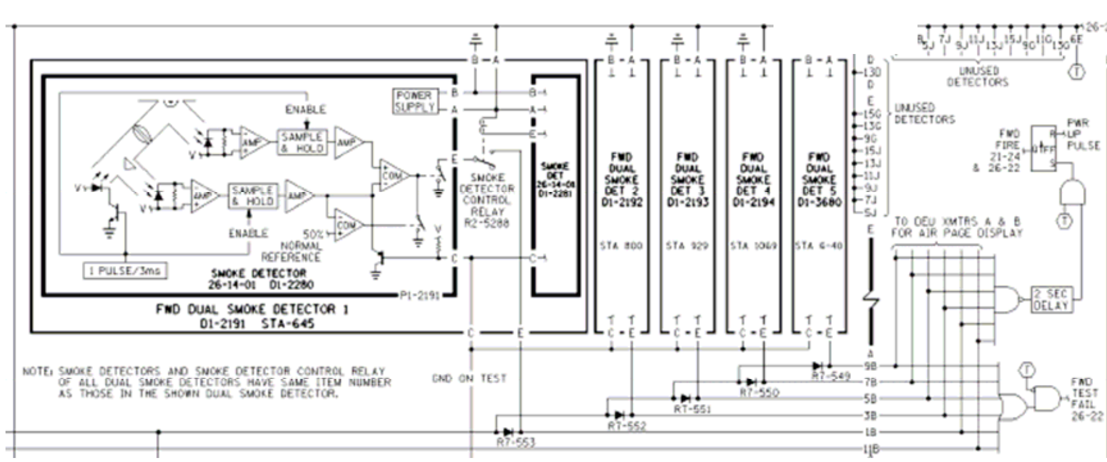


Appendix Figure D10 Cabin Cargo Fire Detection Block Diagram.

Source: MD-11 AIRCRAFT SIMPLIFIED SCHEMATIC 26 - 15 - 00 Page 105 Jul.

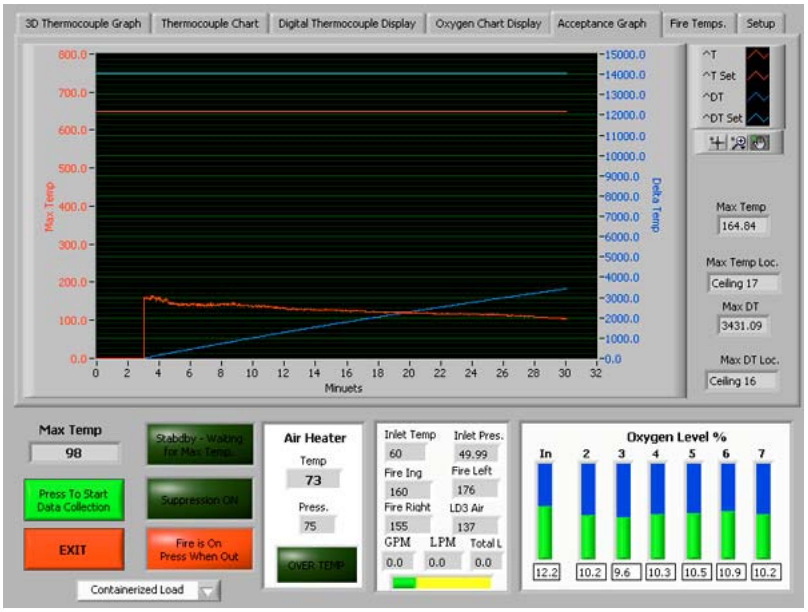


Appendix Figure D11 Cargo Smoke Detection Simplified Schematic Designed.
Source: MD-11 AIRCRAFT SIMPLIFIED SCHEMATIC 26 - 15 - 00



Appendix Figure D12 Smoke Detectors Control Schematic Diagram.
Source: MD-11 AIRCRAFT SIMPLIFIED SCHEMATIC 26 - 15 - 00

The results of the Early Warning Fire Detection (EWFD) prototype Series 1, tests conducted on the ex-USS Shadwell over the period of February 7-18, 2000.A series of tests was conducted to evaluate and improve the multivariate data analysis methods and candidate sensor suites used for the Early Warning Fire Detection (EWFD) system under development. The EWFD system is to provide reliable warning of actual fire conditions in less time with fewer nuisance alarms than commercially available smoke detection systems. Tests were conducted from August 30 - September 3, 1999 onboard the ex-USS Shad well. This report documents the test setup and results from the fire detector used during this test series. [Early Warning Fire Detection (EWFD) Nov.21, 2004 download]
Source: Susan L. Rose-Pehrsson; Daniel T. Gottuk; Jennifer T. Wong; Sean Hart; Ronald B. Shaffer; NAVAL RESEARCH LAB WASHINGTON DC CHEMISTRY DIV.
OCT.27/CONTAINER LOAD MPS



Appendix Figure D13 Rule Change: Cargo-Compartment Smoke Detection & Fire Suppression.

Source: http://pyrogen.com, down load 2004

Concern over the potential for catastrophic in-flight fires in commercial airplane cargo compartments has focused attention on cargo compartments that depend on oxygen deprivation to prevent and suppress combustion (Class D compartments). Though the risk of fire in a cargo compartment is statistically very low, the U.S. Federal Aviation Administration (FAA) has issued a rule change to require airplanes registered in the United States to convert all Class D cargo compartments to Class C or Class E compartments by installing a smoke-detection system (Class E), fire-suppression system, or both (Class C), depending on whether the airplane is a passenger or freighter configuration. Boeing has been supplying the information and installation hardware that operators need to meet the rule change deadline of March 18, 2001.

For many years, commercial airplanes have relied on oxygen deprivation to control the risk of cargo-compartment fires below the main passenger cabin. However, a cargo fire in a commercial airplane that resulted in hull loss has caused the perception of cargo-fire risk to grow. In response, the U.S. Federal Aviation Administration (FAA) issued a rule change on March 18, 1998, that mandates the conversion of Class D compartments to

Class C or Class E compartments by installing smoke-detection systems, fire-suppression systems, or both.

Boeing is positioned to help commercial airplane operators meet the rule change deadline of March 18, 2001. The Boeing support plan is based on

- Historical and recent use of Class D compartments.
- Current criteria for Class C compartments.
- Current criteria for Class E compartments.
- Technical assistance available to operators.
- Tested and validated design.

Benefits

Method that prevents fire on commercial aircraft, helping airlines save money, to improve safety, ensured compliance and greatly reduced on-ground delays. Many of the world's major airline carriers, which have been recognized by airline executives, engineers, pilots, maintenance crews and industry analysis for their superior technology, easy to installation, and rapidly return on investment.

Solutions use state-of-the-art technologies to remove the ever-present threat of fire on commercial aircraft improve airline safety, ensure compliance with FAA regulations and greatly reduce delays, thereby enabling airlines to focus on faster turns and use their aircraft more efficiently. On ground and in the air, commercial aircraft is more cost-effective to operate and safer to fly.

Funding Source

Budget: Some of funding at the beginning of the project which my project will be "phase up" over a period of time but no one approach yet, how ever I can still use all of those equipments or materials from Thai Airways Company Co. Ltd. (Public) and some from the other Airline companies who let me use instruments during my routine tasks trouble shooting took place at that aircrafts parking for maintenance checking time (period).

A suggested budget format for eight months maximum funding proposal:
For itemizing my budget are:

- Personal (my colleague, salary and benefits)
- Rental of facilities
- Travel
- Communication (telephone)
- Equipment (some can loan from the suppliers)
- Materials preparation
- Other expenses
- Indirect cost (my working time; days absence code without pay, and vacation days without overtime activation)

Appendix Table D1 Timetable

Planning Procedure	2005									
	Jan.	Feb.	Mar.	Apr.	May.	JUN.	JUL.	AUG.	SEP.	OCT.
1. Prepare a comprehensive review of the literature	—	—	—							
2. Discuss my research with others			—	—	—					
4. Reliability with mathmatical programme					—	—	—	—	—	—
5. Rewrite my proposal into dissertation sections						—	—	—		
6. Review other dissertation before writing				—	—					
7. Writing the Research Paper						—	—	—	—	
8. Conclusion Research and Report Process									—	—

Places and Duration ———

Place; At Donmaung Airport air-site, Ramp or area that aircraft parking bays for maintenance and/or prepare to operate flight where we are In the passengers cabin and also in both cargo compartments of the Thai aircraft fleets with all aircraft types of Boeing and Airbus which are commercial aircrafts of Thai Airways International Co. Ltd. (public). Some aircraft type even they had been designed with the separated long cargo compartments called forward cargo compartment and center cargo compartment both are designed under floor of passenger cabin which there are several configuration cargo doors on the right hand side of the fuselage and they also were separated or partitioned providing by the center fuel tanks almost and aft (bulk) compartment additional.

Duration 23 weeks; Start from January 05,2005
Finish on October 24,2005

Appendix Table D2 Budget Planning

	Jan; 2005-Feb; 2005	Mar; 2005-May; 2005	Jun; 2005-Oct; 2005
Personnel			
Person #1			
Person #2			
Sub-Total			
Facilities (list)			
Sub-Total			
Equipments (list)			
Sub-Total			
SUPPLIES (list)			
Sub-Total			

Source: http://www.fire.tc.faa.gov/conference/pdf/DBlakeCargo.PDF
; Philippe Mangon Cerberus S.A, BUC, France
>> Fire Detection for Aircraft Cargo Compartments, Reduction of False Alarms
>>http://fire.nist.gov/bfrlpubs/fire01/PDF/f01049.pdf/
http://www.airlinesafety.com/faq/faq9.htm
http://www.fire.tc.faa.gov/pdf/systems/Reinhardt-CargoCompartmentMPS.pdf