FIRE PROTECTION

Engineering

1ST QUARTER 2013

Issue No. 57

AIRPORT TERMINAL DESIGN

Fire Safety Issues

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Airport Terminal Design – Fire Safety Issues

A case study of the fire safety design for Dublin Airport's Terminal 2, with emphasis on the Qualitative Design Review (QDR) phase.

By Barbara Lane, Ph.D., CEng., William Ward, and John Noone, all with Arup

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1ST QUARTER 2013

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From the TECHNICAL DIRECTOR

Compensation Data for Fire Protection Engineers in 2011

In late 2011, the Society of Fire Protection Engineers conducted its biennial compensation survey of the fire protection engineering profession. A total of 745 people from 41 countries responded to the survey, with the majority (86%) living in the U.S. (Canada had the second largest number of respondents, accounting for 3% of the responses to the survey.) Overall, the survey found that the median salary of fire protection engineers increased 2.9% over the median salary in 2009. Even during the current difficult economy, fire protection engineers saw an increase in their salaries.

The number of fire protection engineers who are unemployed (6.2% at the time the survey was conducted) is a decrease from the 7.2% who indicated that they were unemployed at the time the 2010 survey was conducted. In the U.S., 5.5% indicated that they were unemployed at the time the survey was conducted in 2012, which was well below the national unemployment rate.

The median total compensation earned by fire protection engineers with zero to two years experience was about $60,000, which increased markedly to over $75,000 for those with three to five years of experience. The median total compensation showed a steady increase during the first 20-25 years of experience, at which it reached a plateau (at approximately $125,000 per year). However, salaries at the 75th and 90th percentiles continued to increase beyond the 25th year of experience, ultimately reaching a 90th percentile value of $217,200 for fire protection engineers with 31 to 35 years of experience. Incentive-based pay accounted for a significant amount (a median of 8.3%) of compensation earned by fire protection engineers.

As one would expect, salaries steadily increased with increasing job responsibility. Fire protection engineers with the lowest level of job responsibility received a median total compensation of $62,000 per year, while those with the highest level of responsibility received a median total compensation of $150,000 per year.

Compensation varied somewhat with the employment sector in which fire protection engineers worked. Overall, 43% of respondents worked in consulting, 21% worked for local, state or federal government (excluding the fire service), 14% worked for insurance companies, and 5% worked for the fire service. In general, fire protection engineers who worked in the insurance industry received the highest compensation (about 8% higher than those who worked in consulting). Fire protection engineers who worked for government agencies received about the same amount of compensation as those who worked in consulting, while those who worked for a fire service received about 20% less compensation than those who worked in consulting.

The level of education influenced the median compensation earned by fire protection engineers. Fire protection engineers with a master's degree had a median total compensation that was from 3% to 14% greater than that earned by fire protection engineers who only had a bachelor's degree, with the greatest differences occurring for fire protection engineers with 10 or less years experience and for those with 26 or more years of experience.

As with prior surveys, earning a professional engineers license had a significant influence on the total compensation earned by fire protection engineers. Fire protection engineers who had a P.E. license earned about 20% more than those who did not have a P.E. license.

The country in which an engineer worked also had an impact on the compensation earned by fire protection engineers; however, due to the low number of responses from countries other than the U.S., these results should be viewed skeptically. Fire protection engineers from the U.S. and Canada earned comparable total compensation ($113,500 and $111,000, respectively). However, fire protection engineers in New Zealand earned less ($93,000) while those in Australia earned more ($219,000). (All values adjusted to U.S. dollar equivalents.)

The full report is available free-of-charge to SFPE members in the SFPE Knowledge Network (available at *www.sfpe.org*).

Morgan J. Hurley, P.E., FSFPE
Technical Director
Society of Fire Protection Engineers

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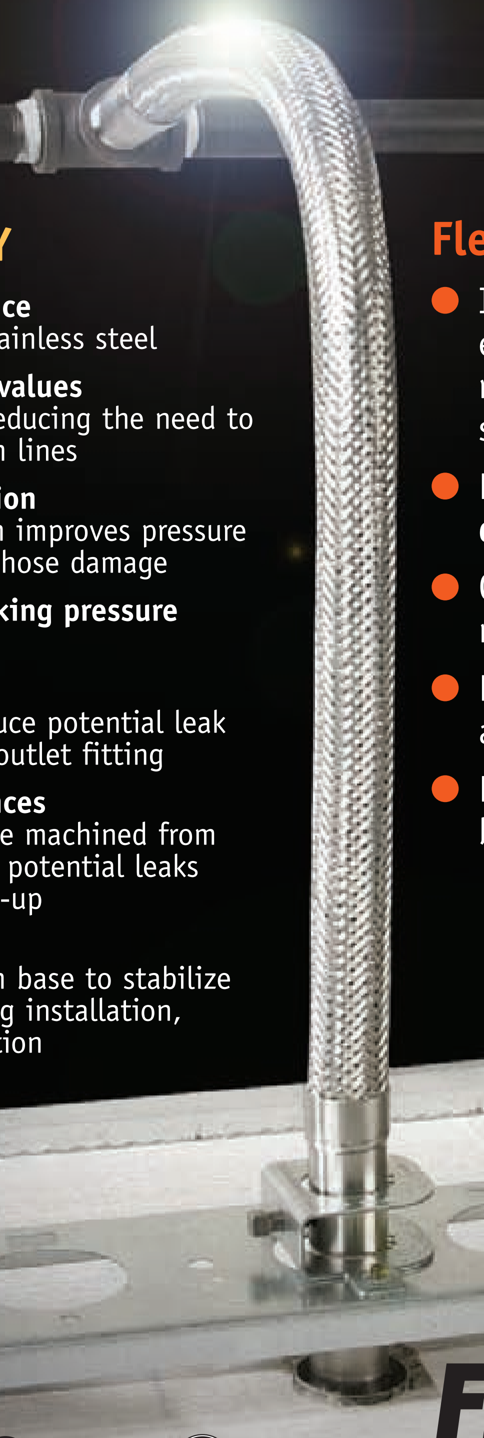

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By Wayne D. Moore, P.E., FSFPE

Almost 10 years ago, on the night of Feb. 20, 2003, the band Great White, known for its heavy metal music, took the stage at The Station nightclub in West Warwick, R.I. As the lead singer, Jack Russell, began his "signature" song, Daniel Biechele, the band's road manager ignited "gerbs"—a form of heavy-duty sparklers. Thus began the worst fire in the history of Rhode Island.

The sparks from the gerbs immediately ignited the "egg-crate" foam the owners had glued to the walls and ceiling surrounding the stage to provide sound deadening to appease the neighbors of the club. Extremely over-crowded, the club held an estimated 462 occupants. The concertgoers had to jam their way through non-code conforming exits. As a matter of interest, someone visiting the site of The Station nightclub and looking at the footprint of the building would immediately ask, "How could so many people occupy such a small building?"

Most of us in the fire protection engineering profession have, at one time or another, read a report about a fire to determine what we could learn from the incident. In fact, we know that after large-loss fire the building and fire codes usually change. Moreover, these changes normally occur because we did not anticipate how the fire happened or why it grew so large or so fast.

But, ineffective codes did not influence the severity of The Station fire. According to the author, John Balyrick, it happened due to the greed and arrogance of the club's owners, ineptness and negligence of the band responsible for the pyrotechnics, and ineffective administration and enforcement of the existing codes and standards, as well as ineffective training of the inspectors responsible to enforce those codes and standards.

Barylick, the lead attorney for the plaintiffs' steering committee, provides insight to the history of the small state of Rhode Island (pop. 1.051 million in 2011) as well as West Warwick (pop. just over 29,000 in 2010) and the club itself. He describes "how things get done" in the state, the interconnectedness of all the people involved, putting a human face to not only the survivors but also to those who created or allowed the conditions that ultimately resulted in the deaths of 100 people.

Barylick walks the reader through the legal system in Rhode Island as it was at the time just after the fire and describes the frustrations of the survivors at not getting justice when those that injured or killed their loves ones, with one exception, walked free or with minimal punishment from the justice system.

In addition Barylick describes how the plaintiff's fire investigation team helped the legal team who, in turn, served the survivors of the fire. You will find that it takes not only keen legal minds to develop a case resulting from a fire, but a relentless fire investigation team combing over the facts and evidence uncovered during their investigation long after the initial investigators gave what they thought were all the answers.

As with any tragedy of this magnitude, we always question how this could happen today. The author clearly and convincingly explains why this fire happened and why the results developed as they did. In addition, in a manner that teaches the importance of the process, he brings the reader through the development of the civil litigation after the criminal proceedings ended. In Barylick's own words:

> "...the tragedy spurred improvements to Rhode Island's fire code...To their credit, Rhode Island lawmakers ended the pernicious practice of 'grandfathering' older places of public assembly that do not meet current code, requiring sprinklers in all gathering spaces with occupancies over 300, regardless of their vintage. This change alone may prove lifesaving for future generations."

Of course the question begs, why did we wait for this tragedy to happen to make the decision to be more fire safe?

A makeshift memorial to all those who died has been established on the site of The Station nightclub and marks the location of this horrific tragedy. After years of discussion, the owner of the site has agreed to donate it to the Station Fire Memorial Foundation so they may erect a permanent memorial. Other memorials serve to remind us of this tragedy at St. Ann's Cemetery in Cranston, R.I. and in neighboring Warwick, R.I. (To see an image, visit *http://magazine.sfpe.org/viewpoint/viewpoint-36.*)

This book should be required reading for anyone in, or planning to enter, the fire protection engineering profession. In a clearly readable and understandable fashion, this book shows how things go wrong seemingly from "insignificant" decisions. If you are a student, read this book. If you are a long-term professional, read this book. And then when you go about your everyday work in our profession, remember this book and what it taught you.

Review by Wayne D. Moore, P.E., FSFPE

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WPI Honored for Developing Technology that Increases Firefighter Safety

Worcester Polytechnic Institute (WPI) was honored at the 23rd Annual "Firefighter of the Year" award ceremony with the 2012 State Fire Marshal's Award, which recognizes significant contributions to the fire service made by those outside of the service.

"For more than a decade, a group of WPI faculty has been diligently working to develop technologies to protect our first responders," said Dennis Berkey, president and CEO of WPI. "They have worked closely with the Worcester Fire Department, with federal researchers and with industry to move this important work forward. This award recognizes their hard work and it echoes the pride that the entire WPI community feels for this exceptional team."

NIST Strategic Roadmap Aims to Reduce the Nation's Fire Burden

Fires claim more than 3,000 lives a year, injure more than 90,000 firefighters and civilians, and impose costs and losses totaling more than $300 billion—equivalent to about 2% of the nation's gross domestic product.

Researchers at the National Institute of Standards and Technology (NIST) have developed a plan to significantly reduce that burden over the next two decades. *Reducing the Risk of Fire in Buildings and Communities: A Strategic Roadmap to Guide and Prioritize Research*, sets short-, medium-, and long-term goals — from fewer than three years to more than eight — for reducing the nation's fire burden by a third.

The publication is available at *http://tinyurl.com/aqoksy6.*

ICC Recognizes NFPA's National Electrical Code®

The International Code Council has designated NFPA 70®, the *National Electrical Code®* (*NEC®*) as the electrical code for use with the ICC's International Family of Codes or "I-Codes." The set of 15 I-Codes are model building codes used in every state and most jurisdictions. Similarly the NEC, which is developed by the National Fire Protection Association (NFPA), is the model code used as the basis for electrical regulations throughout the country, and it has been referenced for more than 10 years in the I-Codes as an integral part of the building safety framework.

"Sprinkler Saves" Blog Records 500 Saves

Viking Group's "Sprinkler Saves" blog recently recorded its 500th recorded "sprinkler save."

The "Sprinkler Saves" blog recently celebrated its one-year anniversary. Fire sprinkler success stories from throughout North America are posted daily to the blog. One of the goals is to influence how the media reports on successful sprinkler activations to help the public gain perspective on the value of automatic fire sprinklers in saving lives and property. The 500th blog entry analyzed the 500 "sprinkler saves" and provided statistics such as:

- 197 (39%) of the 500 saves occurred in residential occupancies
- 37 occurred in nursing homes or senior living facilities
- 22 were in hotels/motels
- The activities of 40 arsonists were foiled due to a successful sprinkler activation.

For more information, go to *http://sprinklersaves.blogspot.com.*

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AIRPORT TERMINAL DESIGN

FIRE SAFETY ISSUES

By Barbara Lane, Ph.D., CEng.,
William Ward and John Noone

INTRODUCTION

Airport fire safety design poses unique challenges for the fire protection engineer. There are few other building types whose dominant focus is a full operations cycle involving large numbers of public occupants as well as a complex support system to enable the building function (retail, baggage handling, security, and so on). To enable this interaction, architecture becomes key in creating tall, open front-of-house spaces and enabling high-frequency operations back-of-house—all in a specific departures and arrivals cycle running in parallel. This remains true regardless of the geographic location. This article presents a fire safety design approach, using the fire protection engineering process outlined in BS 7974,[1] to highlight the key items that can create a practical airport terminal fire safety design.

Over the years, the fire protection engineer has played a role in airport design—seen as an enabler of the operational and design features. Success relies on integration with the other design team members and stakeholders. With operational requirements and signature architecture forming a fundamental basis of the project, close communication with the airport operator, their fire safety management team, as well as the architect, from the very conceptual stages, have proven to be fundamental to the successful design and implementation of an airport terminal fire safety design.

The fire protection engineer has a substantial role from concept stages, right through to design, quantifying the agreed principles and being part of the specification stage and onwards to construction and design compliance on-site. For airports (like many other complex buildings and one could suggest, in fact, any building), a robust strategy for commissioning the fire and life safety systems

> Irish legislation, until recent amendments were introduced, required that site works could not commence without prior approval of fire safety design in the form of an approved "Fire Safety Certificate" from the fire authority.

and inspecting the key elements for completeness, as well as participating in the training and handover of a functioning fire strategy, is increasingly a required part of the fire protection engineer's role.

A recent project at Dublin Airport (Terminal 2) in Ireland illustrates pertinent fire safety issues relating to the design and, ultimately, the successful delivery of an airport terminal.

Terminal 2 is located to the east of the existing Terminal 1. The building consists of a seven-story main terminal building of approximately 70,000 m² and a three-story Pier E building of approximately 20,000 m² in area. The state-of-the-art terminal is capable of handling up to 15 million passengers per year. At its peak, Terminal 2 was the largest construction project in the state and employed up to 2,600 workers on-site. Importantly, the terminal was built in a live airport environment creating substantial logistics re-alignment on the site to enable continuity of operations.

The initial fire strategy concept began in 2006, culminating in completion of the final as-built fire strategy revisions in 2012.

Irish legislation, until recent amendments were introduced, required that site works could not commence without prior approval of fire safety design in the form of an approved "Fire Safety Certificate" from the fire authority. Revised certificates were subsequently required in order to reflect the as-built form. A change control method was adopted so that the fire protection engineer could review

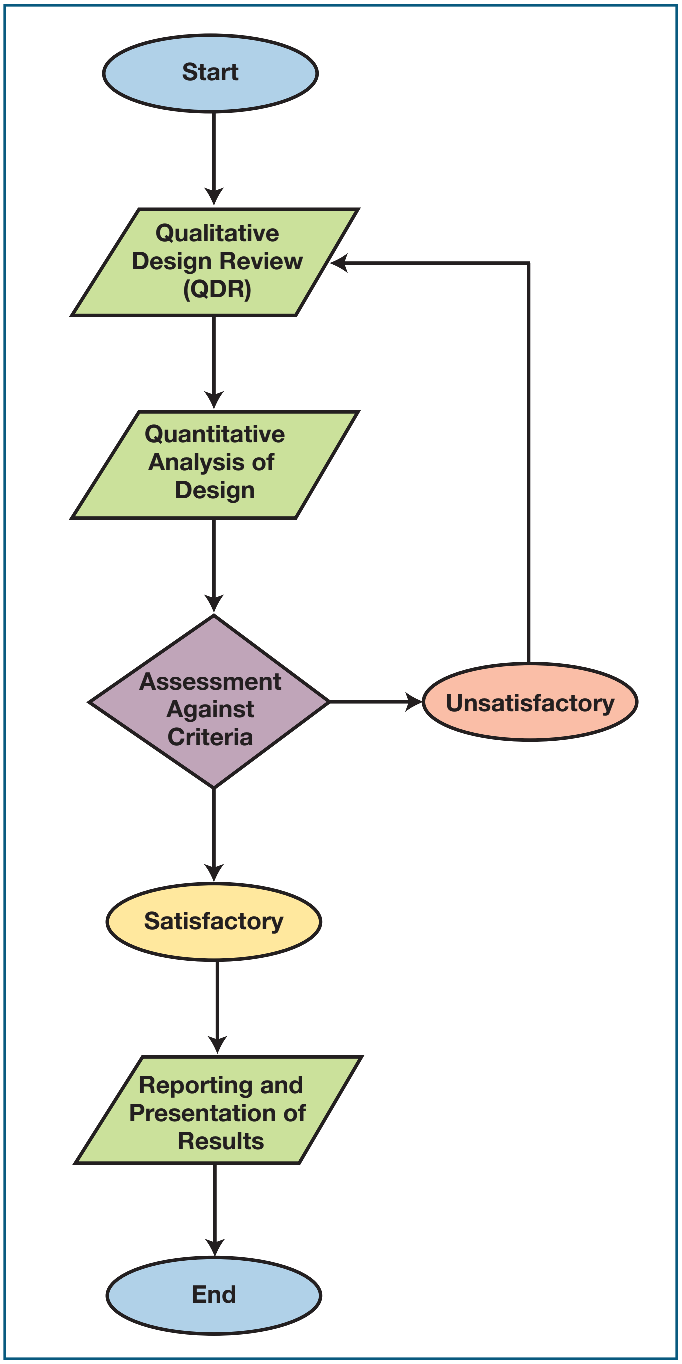

Figure 1. QDR Process

changes as they arose and subsequently address them with the fire authority. Such changes included architectural design development and modifications arising from on-site construability issues.

THE FIRE PROTECTION ENGINEERING PROCESS

Airports, due to their design, necessitate the adoption of a fire protection engineered approach as opposed to following the recommendations of prescriptive guidance.


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BS 7974 provides a basic framework for the application of fire safety engineering and is similar in that regard to the processes set out in other contemporary performance-based design guides such as that developed by SFPE.[2] This approach is illustrated in Figure 1.

The guidance recommends four main steps in the process:

1. Qualitative design review (QDR)
2. Quantitative analysis of design
3. Assessment against criteria
4. Reporting and presentation of results

While all of these stages are important in developing a robust strategy, it is during the QDR stage where the parameters that can create a successful fire safety design are created. If the key items are not known or identified during the QDR, the remainder of the process will suffer.

The remainder of this discussion will use the challenges met during the design and construction of Terminal 2 as an example of items that should be identified and addressed during the QDR stage.

THE QUALITATIVE DESIGN REVIEW (QDR)

BS 7974 identifies the main stages in the QDR process as the following:

a. Review of architectural design and occupant characteristics,
b. Establish fire safety objectives,
c. Identify fire hazards and possible consequences,
d. Establish trial fire safety designs,
e. Identify acceptance criteria and methods of analysis,
f. Establish fire scenarios for analysis.

Stage / Team	Concept	Design	Construction
Client (including client bodies such as security, retail, customs, etc.)	Understand operational goals & agree on business continuity objectives. Communicate concept fire strategy.	Communicate detailed fire strategy and any operational implications. Clearly outline fire safety management requirements. Hold workshops with client bodies as required.	Close collaboration during Operational Readiness Activation Transition (ORAT) phase to understand client needs. Provide for the safety of occupants within the building prior to completion. Advise on legislative health & safety implications.
Architect	Understand architectural aspirations & communicate concept fire strategy.	Communicate detailed fire strategy & hold design workshops to develop integrated solutions. Illustrate fire strategy on drawings. Agreement of construction details.	Approving benchmark construction details and assisting with site inspections. Assistance with problems encountered on-site.
Mechanical, Electrical & Plumbing (MEP)	Understand concept MEP strategy & communicate concept life safety systems strategy.	Communicate detailed fire strategy & hold design workshops to develop integrated solutions.	Assist and witness systems commissioning. Assist with site inspections.
Dublin Fire Brigade	Agree on main fire strategy principles.	Hold meetings and workshops as necessary to agree on detailed strategy. Gain formal strategy approval.	Additional approvals if required.
Insurer	Understand main insurance objectives.	Communication and agreement of detailed strategy.	Verify that insurance goals are maintained.
Construction Manager			Impart fire strategy principles and importance of quality during construction. Regular liaison to prioritize areas of work depending on client needs (e.g., ORAT). Assisting with construction quality assurance.
Main Contractor			Agree on benchmark details. Close liaison to agree on solutions to problems encountered during construction.

Table 1. QDR Team Members and Responsibilities

The team formulated to carry out this process is key to the success of the final fire safety design and is discussed below.

The QDR Team

Through design and delivery of the T2 project, the interaction between the various teams and people involved was found to be fundamental to proper design and delivery. Table 1 illustrates the relevant teams and their importance at each stage.

Review of Architectural Design, Occupant Characteristics & Fire Hazards

BS 7974 advises that the following be considered in relation to the architectural design and occupant characteristics of the building: building structure and layout, use(s) and contents of the building, fire service access to the building, occupants, ventilation systems, unusual fire hazards, planning constraints and client requirements, including possible future options.

> The airside environment of an airport is a highly controlled area, with all staff and tenants operating under strict procedures and everyone (including members of the public) being limited in terms of the items they can transfer across the airside/landside line.

The Building, its Uses and Hazards

Passenger experience is key to the architectural design aspirations behind an airport. The fire strategy must facilitate this process. The resultant architectural design typically consists of large and high, open spaces front-of-house for the public, with little or no physical separation between each area to allow a smooth transition for passengers from function to function (check in, security, retail, departure; and the reverse function of arrivals, immigration, baggage pickup, retail, arrivals and onwards travel). Physical separation is required to separate back-of-house from front-of-house.

Security and immigration create spaces where a single direction of forward travel must occur, and mixing of occupants at different stages in their journey must be prevented. The most important "line" in the airport terminal is the landside to airside line. This can be physical in parts (particularly through back-of-house) but front-of-house this tends to be a mix of physical barriers and staff-controlled processing lines. The evacuation strategy must accommodate this, and prevent mixing of processed and unprocessed passengers, as well as a major reprocessing of passengers in the event of an evacuation.

Front-of-house consists of large, high, open spaces, which may also be subdivided from an evacuation perspective to control safe escape and minimize interruption. In the absence of a physical subdivision, the role of active smoke control systems and fire hazard and control strategies becomes central to the fire safety design.

The identification of fire hazards and how they are mitigated are therefore central to the fire safety design. Terminal 2's high-volume, open plan, front-of-house areas relied on a strategy that was based on either suppression or the creation of maximum permitted fuel load sizes and locations in areas where smoke from a fire could rise directly from a fire to the ceiling above (ranging from 10-40 m in height).

The airside environment of an airport is a highly controlled area, with all staff and tenants operating under strict procedures and everyone (including members of the public) being limited in terms of the items they can transfer across the airside/landside line. It is unusual to have a public building where the fire load can be so well defined.

One area of an airport terminal that requires detailed consideration is the baggage handling area. This is where luggage is either sent to the planes from the check-in desks or received from the planes and sent to the baggage reclaim carousels. It generally consists of a large volume with many baggage conveyors, sorters, platforms, walkways, open stairs and mezzanines. Challenges encountered in this area include: treatment of connections to steel work, appropriate means of escape signage in a highly complex environment, maintaining compartmentation between the handling hall and other parts of the terminal, and providing acceptable travel distances for the trained staff occupying the space.

Unusual fire loads need to be envisaged during the QDR also, specifically in areas with high ceilings (i.e., >10-15 m), such as Christmas trees or marketing promotion stands (e.g., cars on display). As always, the flexibility of retail requirements needs to be considered, as unrealistic fuel load controls from a fire strategy will cause implementation problems and an unrealistic and potentially unsafe approach as a basis for a fire strategy. That is why the retail team was constantly involved in fire strategy decision making. For implementation, a set of fuel load drawings were created and approved under the process with Dublin Fire Brigade, which illustrated to the client what type of fuel load could be located in each area and which areas had to be sterile.

The strategy adopted for each area was:

- Back-of-house areas. There was a need for all back-of-house areas to be physically separated from the remainder of the building for security purposes; therefore, traditional compartmentation was adopted.
- Retail areas. A cabin concept approach was adopted based on automatic sprinkler protection and localized smoke control designed to prevent smoke spilling to other areas.
- Front-of-house areas underneath mezzanines were provided with sprinkler protection, and smoke control was provided underneath the floor slab to limit smoke spread to other levels.
- Front-of-house areas not directly below a floor slab in which smoke from a fire could rise to roof

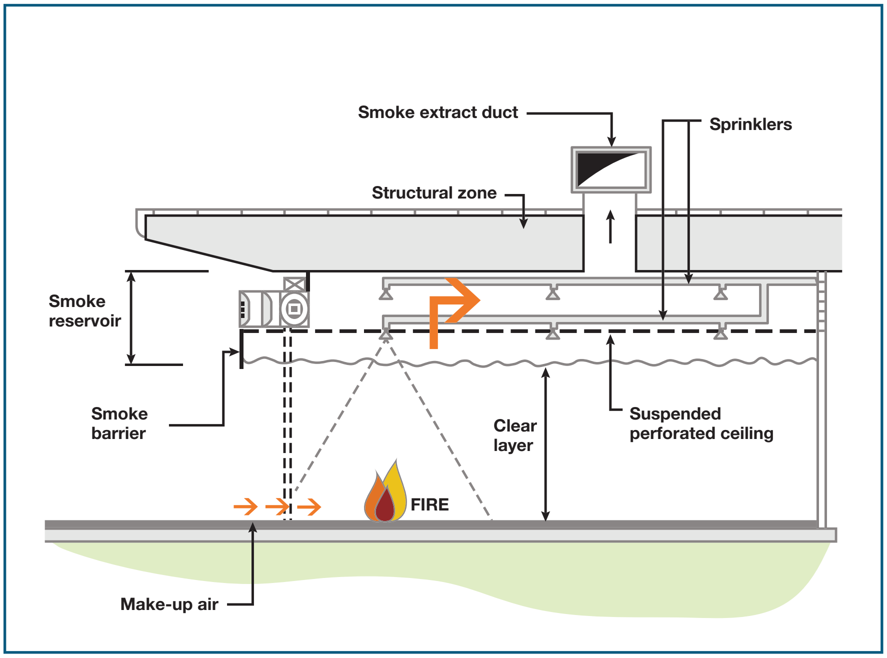

Figure 2. Cabin Concept

level were subject to fuel load control limits, depending on the maximum size of fire that could be expected either due to an open retail kiosk or luggage fire.

The cabin concept approach referenced above relates to a method commonly adopted in large-volume buildings in which the fire load is located within cabin-like structures. A retail unit within a shopping center or airport is a prime example.

The approach is based on the provision of a ceiling void that acts as a smoke reservoir, as shown in Figure 2. The provision of automatic sprinkler protection limits the fire size and volume of smoke produced. Smoke extraction is designed to limit any spread out of the cabin. The cabin concept is a useful approach in buildings in which, allowing smoke to flow up to the roof, would result in significant extraction rates. Other benefits include limiting smoke spread (and, therefore, business disruption) to the fire unit and the maintaining of an open-unit frontage.

Fire Service Access

In large terminal buildings, the fire service typically wants to be able to arrive at a single control point to receive a briefing from airport staff and assess the situation before deciding the next steps. From there, they need to be able to access the fire floor within a protected route and get within a reasonable distance of the fire with an adequate supply of water. The means in which they cross the airside/landside line is, therefore, an important consideration.

Terminal 2 was provided with a fire control center within which it was possible to receive live information from the life safety systems, including the CCTV cameras. The control center was separated from the remainder of the terminal with 120-minute fire resisting construction and had dedicated access direct to open air. From the fire control center, the fire brigade could access a total of eight ventilated firefighting shafts with dry mains provided therein. There were also two specific fire service cross-over points within the building through which firefighters only could pass the airside/landside line as well as two external routes. One external route was a passenger gate in the airside/landside fence near the building perimeter while the other was a manned vehicle gate that allowed access to the apron.

The fire control center was provided with control panels for each smoke zone and evacuation area, which allows for full control of evacuation of the affected area. The evacuation can be phased on an automatic or manual basis, or the decision can be taken to simultaneously evacuate the entire terminal from the control room if considered necessary. In addition, a microphone is provided with which direct announcements can be given to occupants.

Dublin Airport has an airport fire brigade who are the first-responders in any incident. Dublin Fire Brigade are secondary responders following a confirmed fire, and there is an agreed approach between each in terms of overall command and the protocol to be followed in an emergency fire situation.

The Occupants

The occupants of an airport terminal are of a broad range of nationalities, mobility abilities, family groups, single travelers, and a wide range of familiarity of travel. All are focused on either departing a flight, or obtaining their luggage on arrival and getting home. Their behavior is key to a successful evacuation strategy.

With such focus on their process, and at peak times in many airports such high numbers of occupants present, the standard total evacuation policy in most buildings can be unrealistic and even unsafe. A phased approach, where a limited number of evacuation zones actually evacuate in a fire, is preferred. This requires that remaining building zones be safe to occupy.

Prescriptive codes assume floor space factors, and resulting exit width provisions. For airports, the occupancy is far more complex, and subject to detailed quantifying by the airport planning team. The fire protection engineer can, therefore, use passenger numbers that are based on the flow of people through the terminal as dictated by the scheduled arrival and departure of flights. The number of support staff supporting the airport services, as well as airline staff, must also be incorporated, and these too are subject to peak flows in a working day.

The type of people within the building and their probable response upon hearing an evacuation message is another factor that the design must take into account, especially if an ASET (available safe egress time) vs. RSET (required safe egress time) assessment is being undertaken. PD 7974-6[3] describes items that will have an impact on the pre-movement time of occupants, which include security restrictions, the possession of luggage, presence of family groups and language barriers.

Another consideration that was taken within the T2 strategy was the possibility of a relatively large number of mobility-impaired persons being present within the terminal. This is due to potential religious groups travelling to Lourdes in Europe, where one party may require assistance at times for up to 130 persons, or sporting events for disabled participants. Additional

overflow disabled refuge areas were provided for within the design to help cater for such a scenario and specific staff procedures put in place.

Key to all of the above is a competent trained fire safety team, and credible reliance on this is key to a successful airport fire design. In the absence of such competence, far less reliance on management must occur.

Client Requirements & Future Flexibility

In an airport, one of the main client requirements is that the building operates as smoothly as possible. When dealing with a terminal building, this means that passengers are processed without delay and security lines are maintained. This was a fundamental challenge within the strategy, and meant that numerous lines throughout the terminal could not be crossed, even in an emergency situation.

An area that deserves detailed consideration is the route the airside/landside line takes through the building. The airside/landside line is the main security line through which all people and objects must pass. Once on the airside (i.e., the departure side) side of this line, a passenger or object has been security cleared and is assumed to be fit for flight. This line may be formed by solid walls, partial walls, doors or simply a space occupied by staff and an x-ray machine. The position of this line needs to be understood fully as it can affect what happens in an emergency situation, including direction of escape, signage and zoning of fire safety systems.

Separating the building into different evacuation areas allowed this challenge to be overcome, and created a solution where occupants do not pass from airside to landside or vice versa in an emergency situation. All escape routes are designed independently of one another. It was another key client requirement that the building could be evacuated as an "all out" function if required, which was also achieved within the design.

Airports are similar to shopping centers in that they are constantly undergoing change due to the large number of third-party organizations and tenant areas within the building. Flexibility was built into the T2 strategy in a number of areas. In addition to conservative figures being assumed for the occupancy of each area, a strategy was developed that negated the need for the provision of fire dampers within air-conditioning ductwork, which passed between retail units.

The strategy for the omission of dampers from the ductwork between the retail units was based on testing undertaken for the Hong Kong International Airport, which showed that smoke within a unit designed in accordance with the cabin concept typically does not exceed 80°C. In addition, the ambient air supply was maintained to provide a positive air pressure within the ductwork, thereby reducing the likelihood of smoke ingress and spread. It should be noted that a fire damper was provided where the ductwork left the retail area.

Another important stage in the project is Operational Readiness Activation Transition (ORAT). A period within which a series of User Acceptance Tests (UATs) are undertaken, the ORAT phase allows end-user groups to conduct their own sets of tests and scenarios in order to build confidence and satisfy themselves that systems are operating as expected. On Terminal 2, this posed a unique challenge as, due to the construction program, beneficial access had to be given to the ORAT team while construction was being completed. It was necessary to provide adequate levels of safety for these occupants under the Irish Safety, Health and Welfare at Work Act. To do so, an ORAT temporary fire strategy was put in place so that appropriate levels of safety were maintained. The ORAT fire strategy, which evolved on a daily basis depending on the construction work taking place that day, entailed:

> At the start of the process, the fire safety goals and objectives were discussed in detail with the client and the approving authority, which allowed a set of acceptance criteria to be established before fire strategy work commenced.

- Prioritization of work in certain areas to facilitate the temporary fire strategy,
- Induction sessions for all RAT staff on fire safety procedures on site,
- Putting in place a number of fire marshals whose sole duties were to enforce the agreed interim fire strategy and to lead the ORAT staff out of the building in the event of a fire,
- Identification and signage of appropriate escape routes remote from construction works,
- The provision of a temporary wireless fire detection and alarm system while the final building systems were being commissioned.

Way-finding trials were also held before the building was fully completed, as part of the ORAT process, which involved

Disruption was limited by evacuating only those areas needing to be evacuated, while maintaining passenger segregation.

multiple events with many (4,000+) members of the public (including mobility-impaired persons and children) being processed through the airport as if they were departing or arriving. Again, a specific fire strategy had to be developed and implemented to ensure participants' welfare.

Fire Safety Objectives & Acceptance Criteria

At the start of the process, the fire safety goals and objectives were discussed in detail with the client and the approving authority, which allowed a set of acceptance criteria to be established before fire strategy work commenced.

Life Safety

It was the duty of Dublin Fire Brigade (the approving authority) to verify that adequate levels of life safety were being met in accordance with the Irish Building Regulations.

The Second Schedule of Part B (Fire Safety) of the Building Regulations[4] requires that adequate levels of life safety be achieved in new buildings by complying with five main functional requirements:

- B1 – Providing adequate means of escape measures. This goal was achieved by carrying out an ASET vs. RSET assessment to demonstrate that untenable conditions would not occur in the time required for occupants to escape.
- B2 – Limiting the potential for fire spread within the building over surface linings, which was achieved by following prescriptive guidance.
- B3 – Limiting the potential for fire spread within the building by limiting compartment sizes and providing

proper compartment construction. Smoke extraction, suppression, fuel load control and active fire safety systems were used to achieve this goal.

- B4 – Limiting the potential for external fire spread.
- B5 – Providing adequate access and facilities for the fire service. This was achieved by the provision of dedicated and protected access routes, building suppression systems and active ventilation.

Business Continuity

Airports operate on a continual basis and are a critical piece of infrastructure. Therefore, large-scale evacuations or disruption of passenger processing in a terminal is catastrophic for the airlines and the terminal operator for commercial and reputational reasons. Business continuity goals were, therefore, established during the concept stage with the client.

The strategy was the protection of sensitive areas or areas of high fire hazard while also providing a response that was in proportion to the event. The philosophy adopted was based on minimizing nuisance alarms by adopting a two-stage cause and effect, which meant that only an evacuation would be automatically instigated following a second activation of a smoke detector. Aspirating smoke detection was also utilized in the baggage handling hall to avoid unnecessary nuisance alarms and implications for the baggage handling system.

If a fire did occur, it was limited as much as possible by the control of fuel load, either by management controlling the size of retail kiosks, etc., or by suppression in the form of sprinklers or gaseous suppression. Disruption was limited by evacuating only those areas needing to be evacuated, while maintaining passenger segregation.

In the unlikely event that a large incident did occur, it was still feasible to initiate a full and simultaneous evacuation of the terminal.

Barbara Lane, William Ward and John Noone are with Arup.

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FIRE PROTECTION OF HISTOR PIERS

By John T. Ivison, P.Eng.

Many of Britain's historic piers are at high risk; in fact, the rate of attrition arising out of catastrophic fires demands urgent action from all those who can assist in their conservation and revival as symbols of Britain's coastal heritage. This article examines some of the key issues in fire protection of these rapidly-disappearing icons of the Victorian age.

Piers encompass a variety of uses. They can be primarily industrial in nature or may be entirely recreational. Some unusual facilities combine promenade facilities with extensive assembly use including, in some cases,

Figure 1. Weston-super-Mare fire – at an earlier stage. (Credit: Weston and Somerset Mercury)

cruise ship facilities or sightseeing and recreational craft. In fire protection terms, such facilities fall in the realm of piers and wharves. This article will focus on historic piers (Figure 1).

The fire hazard associated with such facilities varies depending on the construction type. More modern piers tend to be of reinforced concrete construction due to the high incidence of severe fires in piers that were wholly or partly of combustible construction. However, whatever the construction, certain problems are unique to piers:

- The difficulty in serving the pier with normal infrastructure, particularly water supplies, integrated signalling in an emergency and power for essential services, such as fire pumps.
- Difficulty in achieving access for firefighting purposes. In some instances, this is exacerbated by the configuration of the pier and in some cases by rail or other infrastructure that may impede access onto or on the pier by fire vehicles.
- The potential for uncertain management and deterioration over time.

In the case of combustible piers, fire has the potential to involve the areas below the pier deck. The degree to which this occurs depends upon the progress of the fire and concentration and extent of combustibles in the structure. In some cases, fuel may be restricted to combustible decking. In other instances, the main structural elements may be heavy timber construction; frequently


Figure 2. Site Assessment of a pier prior to major repairs.
(Credit: Gulf of Georgia Cannery Society Archives)


Figure 3. Heavy Timber Sub-Structure under a typical pier.
(Credit: Gulf of Georgia Cannery Society Archives)

this consists of creosoted timber. Often, there is a mixture of construction types (Figures 2 and 3).

The prevalence of windy conditions in seaside locations can contribute to fire spread. Actual fires have demonstrated that fire will spread against the direction of the wind as well as being assisted in the direction of the wind. In one relatively recent fire, in an area involving combustible structure above and below the pier, there was total destruction in the downwind direction in addition to fire spread along combustible decking against the direction of the wind.

In many cases, piers are relatively inaccessible to fire service vehicles. Fires below combustible piers are particularly problematic in that access problems are compounded at low tide by the lack of 'hard standing'. In other words, at low tide, fire vehicles, even if they can access the beach, can become bogged down due to the weight of fire appliances. This leads to fire service delays that may be critical to fire damage.

At high tide, difficulty with the deployment of hoses on the fire, by fire boats for instance, is compounded by tidal and wave action. Substructure may effectively screen the fire from direct impingement of water. Although access is often attempted from above the pier by cutting through the pier deck, it is usually difficult to determine exactly where the fire is due to smoke and other factors. If access hatches are not provided, then fire services have to cut openings into the deck and deploy nozzles designed to extinguish substructure fires.

Typical heavy timber wharf with fender piles.

It is difficult to extinguish fires in this manner. Water supplies are often limited and the number of openings achievable over a fire area may enable the fire (often aided by lack of water penetration by the nozzles and the prevailing wind) to rapidly spread beyond the area of attack.

Structures above the pier deck may be of combustible construction or contain sufficient combustible materials to become involved in a fire and pose a fire risk to the entire structure. In the case of recreational piers, fires often start in the above-grade structures and spread to the substructure, where they burn out of control. Therefore, reliance has to be placed on automatic suppression to mitigate potential fire damage.

Historically significant piers share many of the typical challenges associated with other heritage buildings. Notwithstanding the fire problems above – the challenge is the deterioration of pier buildings and the management of fire risk over time. Superimposed on the usual problems of achieving an acceptable level of fire and life safety (in the context of refurbishment or adaptive re-use) is the so-called 'moral hazard' associated with planning and construction in seaside facilities. While this is a defining characteristic of seaside towns, there is often poor control of fire hazards, compared to more 'organised' jurisdictions. The transitory nature of business and regulatory controls often allows uncontrolled construction changes to occur over time. These often increase the fire risk in probabilistic terms compounded by the ineffective fire safety

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Under the boardwalk at the port of Blyth.

management. This is combined with the increased risk of arson, poor control of recreational fires under piers and other issues.

On a positive note, moves in the UK to take back ownership of piers either by public or private agencies – for conservation purposes – is a sign that the heritage value of certain seaside piers is being recognized. The availability of grants to introduce recommended fire precaution measures is also encouraging.

A complication is the lack of an appropriate standard for property conservation. In England and Wales, for instance, Approved Document B (ADB)[1] to the building regulations, is primarily a life safety document. It offers only nominal property protection measures and often relies on compartmentation and detection to limit fire spread. Compartmentation may often be breached or non-existent due to the age of construction. Extensive combustible concealed spaces may have been created and modifications made with little regard to fire and life safety. Typical fire hazards, such as those associated with deep fat fryers or storage and handling of flammable liquids, are often poorly controlled.

Fire detection relies on effective response to alarms. The assumption that the size of a fire can be limited by compartmentation and the fire risk offset by rapid and effective response to a fire must be seen in the context of access and firefighting limitations on piers. Also, ADB does not address fires below pier, which are often a


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contributory factor in very large fires. The relatively recent fire at Weston-super-Mare showed that the above pier structure itself was so poorly protected that it could be subject to a total loss. So what is the solution?

Sprinklers in above-pier structures require special consideration due to a variety of factors, including their visual impact on historic interiors.

The first consideration is water supply infrastructure. The use of recirculating stainless steel mains is one option to prevent freezing of essential supplies and protecting water supplies from deterioration due to corrosion. Routinely, such systems should be run on fresh water to prevent excessive corrosion, but more importantly, to reduce contamination by marine organisms when saltwater pumps are used.

Victorian pier at Eastbourne in East Sussex in England.

Professional designers use a combination of techniques to integrate the system with the building architecture in order that the fire protection system is not obtrusive.

In a recent case, a test of saltwater hydrants was conducted. It was found that the saltwater system was completely obstructed by fish, seaweed and other solid matter. This had been pumped into the system under normal 'wash down' of decks, ostensibly to prevent re-ignition of discarded smoking materials.

Water supplies should include:

- Where possible direct or indirect use of potable water from the town mains;
- Use of land end (dry side) tanks;
- Duplicate pumps at the dry end of the pier; and
- Use of saltwater supplies as the last resort with effective starting protocols to prevent accidental starting of saltwater pumps in non-emergencies.

In terms of the pier substructure and pier buildings, there is no requirement for the installation of an automatic sprinkler system. Moreover, there is no national guidance document in the UK for fire protection of piers. In lieu of this, NFPA 307,[2] can be used. It is a robust standard that addresses all the typical conditions encountered in piers and wharves.

Substructure sprinkler systems differ in that they typically throw water upwards rather than downwards in order to reach all pockets in the substructure. Careful placement of the sprinklers is necessary to achieve effective wetting of timbers and prevent shielded areas that can permit a path for fire to spread. NFPA 307 relies on the use of bulkheads to control fire spread. This can raise planning issues in listed buildings as the architectural appearance of the pier can be compromised to a degree. In lieu of this, some consideration could be given to extend the capability of the sprinkler systems to deal with fire over larger areas.

Sprinklers in above-pier structures require special consideration due to a variety of factors, including their visual impact on historic interiors. In most areas with suspended ceilings, sprinklers can be concealed.

Typically, the routing of piping has to be designed to reduce the visual impact of piping and sprinklers. Where piping has to be exposed, it can typically be run along beam lines and painted to match adjacent finishes.

Professional designers use a combination of techniques to integrate the system with the building architecture to provide a fire protection system that is not obtrusive. This is a result of collective experience on sensitive occupancies, such as cathedrals and historic houses with decorative ceilings.

The challenges may be problematic when undertaking the installation on a design-build basis. In some instances, contractors may be less concerned with appearance than achieving system costs in order to win the contract. For this reason, retention of a fire protection engineer familiar with pier protection systems and international standards should be considered before embarking on a program for protection, restoration, refurbishment or adaptive reuse of an historic pier or wharf. Most historic buildings benefit from an independent design followed by a close partnership with the selected sprinkler contractor.

John Ivison is with John Ivison and Associates Ltd.

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CHALLENGES OF AIRCRAFT HANGAR FIRE PROTECTION

THE DEVELOPMENT AND USE OF A MODERN STANDARD

By Michael E. Aaron, P.E.

INTRODUCTION

By their nature, aircraft hangars pose unique challenges for the fire protection engineer. There are large, open floor areas with tall roof decks to house high-value aircraft contents. Large quantities of liquid jet fuel are present, and aircraft maintenance activities offer a variety of potential ignition sources.

Another characteristic that differentiates hangars from most other occupancies are the large aircraft wings and fuselages that create obstructions to both fire detection and fire suppression. Sometimes, there are large scaffolds, which create further obstructions.

Naturally, as hangars come in all shapes and sizes, some of these features are not always present. A 6,000 ft^2 (560 m^2) shelter for small aircraft poses different challenges than a 150,000 ft^2 (14,000 m^2) maintenance complex for overhauling commercial jets.

The main fire threat is posed by a fuel spill finding an ignition source, leading to a challenging fire. A 50 foot (15 m) diameter pool of burning Jet-A fuel can produce a heat release rate on the order of 300 megawatts. A few hundred gallons (liters) of ignited fuel is enough to destroy just about any facility that is not properly protected.

Large hangars call for suppression systems on a scale with which some engineers may be unfamiliar. Fire detection systems must function over unusual heights and distances. Sensitivity is needed for fast response, but this factor must be balanced against protection from nuisance alarms. There are a number of fire suppression options, most of which involve fire pumps, foam systems and sprinkler systems with large design areas. Zoning and distances from equipment rooms to discharge points can also create design complications.

No less challenging for the fire protection engineer is the task of guiding a client or employer, whether that be building owner, construction contractor, code official, A/E firm, etc., through the often confusing array of design options and code requirements. The code requirements are far reaching and have big cost implications. The costs can be hard to reconcile against the loss history data. Hangar fires are low-frequency, but high-consequence events, and the codes require a large amount of protection and redundancy.

NFPA 409, *Standard on Aircraft Hangars*,[1] is the primary document where adopted by the local jurisdiction. Like all NFPA codes and standards, NFPA 409 becomes a legal requirement when referenced in an adopting

ordinance by a local governing body. Sometimes, these ordinances include amendments to certain provisions of the document. Even when not specifically adopted, there is often a desire to conform to internationally recognized minimum standards. Where insurance requirements govern, compliance with FM Global standards may be important. For U.S. military projects, matters depend greatly on which branch of service is involved, as there are differences between criteria from the Air Force, Navy, Army and National Guard. This article focuses on NFPA 409.

HISTORICAL PERSPECTIVE

In the 1950s, NFPA began producing what became NFPA 409, taking the place of the earlier pamphlet from the National Board of Fire Underwriters (NBFU). Early NFPA hangar fire protection systems for larger hangars were based on sprinklers. The requirement became deluge-type sprinkler systems (with open sprinklers), and allowed a choice of plain water or foam. If foam was chosen, lesser sprinkler densities were allowed. Protein-based foams and fluoroprotein foams were used, as well as synthetic foams, which became the AFFFs (aqueous film forming foam) of today.

Draft stops (curtains) and floor drainage were important parts of the protection scheme, so the deluge flows could wash the burning fuel safely off the floor and down the drains. In the 1950s and 1960s, large deluge sprinkler systems were the norm. Rows of original deluge risers are often found in hangars constructed during this era. They employed pilot sprinklers or drop-weight mechanisms to open the

> Because of their physical properties, foams stay above and cling to the surface of burning fuels with a smothering action that provides cooling, cuts off oxygen and suppresses fuel vaporization.

valve clappers. The weights were released by low pressure pneumatic heat detection systems connected to a network of heat-actuated devices (known as HADs) installed beneath the roof deck.

The old deluge systems covered sprinkler zones of up to 15,000 ft^2 (1,400 m^2) that were separated by draft curtains. They had design densities of 0.16 to 0.25 gpm/ft^2 (6.5 - 10 mm/min). The number of simultaneously flowing zones to be hydraulically calculated was determined by what was known as the "radius rule." The higher the roof deck, the larger the radius of an imaginary circle drawn in the plan view. Any zone touched by the circle had to be included. Hangars with 4, 5 or 6 zones calculated flowing were common, leading to huge sprinkler design areas of 90,000 ft^2 (8,000 m^2) or more.

With the advent of wide-body aircraft with expansive wing areas, such as the Boeing 747, the NFPA 409 committee became concerned that the aircraft would shelter a fire from the sprinkler discharge, and the water or foam would be too slow to reach the fire. They saw the need for foam to be discharged directly beneath the aircraft. With the 1970 edition, NFPA 409 began requiring "supplemental" foam systems in addition to the deluge sprinklers where there were individual aircraft with shadow areas greater than 3,000 ft^2 (280 m^2). Supplemental systems almost always employed oscillating monitor nozzles. (High expansion foam is also an option.) Though these nozzles need to only cover the area beneath the aircraft, as a practical matter they must cover a considerably larger area in order to reach all parts of the irregular shape of the aircraft shadow.

In the 1970s and early 1980s, Factory Mutual conducted research that led to the conclusion that sprinklers discharging plain water would fail to control a pool of burning jet fuel on a hangar floor.[2] Increasing sprinkler densities was not the answer, since fuel rises above water and can continue to burn or vaporize and reignite.

Because of their physical properties, foams stay above and cling to the surface of burning fuels with a smothering action that provides cooling, cuts off oxygen and suppresses fuel vaporization. Therefore, starting with the 1985 edition, NFPA 409 eliminated the option of plain water deluge sprinklers for Group I hangars, allowing only foam-water deluge sprinklers.

In the late 1990s, the NFPA 409 committee was presented with research conducted by the U.S. Navy.[3] This led the 2001 edition to incorporate the most significant changes to Group I hangars since the foam requirement. The traditional foam-water deluge sprinkler scheme was retained, but as just one of three possible options. The old radius rule governing these deluge designs was revised to be independent of roof height.

The two new options were variants of the Group II protection requirements. In these new options, closed-head sprinklers are used at the roof level, and foam systems, either low-expansion or high-expansion types, are employed to cover the entire hangar floor area. These are termed "low-level" foam systems.

Thus, the general historical trend has been to reduce the role of sprinklers from the primary fire suppression system, to a system to cool the steel while a foam system blankets the floor.

UNDERSTANDING AND APPLYING NFPA 409

The first step in applying NFPA 409 is to address the basics: will the aircraft in the hangar always be unfueled? What "group" should this hangar be classified as?

Allowing only unfueled aircraft in the hangar reduces protection requirements to a simple hazard sprinkler system. Most owners find this unacceptable for their operations. Fueled aircraft are the norm. Regarding hangar groups, rules-of-thumb (full details are in the standard) are as follows:

- If the aircraft bay is greater than 40,000 ft^2 (3,700 m^2) and/or if the hangar door is taller than 28 feet (8.5 m), it's a Group I (the most severe case).
- If neither condition is true, it's a Group II (only somewhat less severe, still lots of requirements, including foam and sprinklers).
- Unless it's a lot smaller (12,000 ft^2 [1,100 m^2] or less for common construction types), in which case it's a Group III. (Few requirements: no sprinklers or foam, no fixed fire suppression systems at all, as long as there are no hazardous activities such as welding, painting, etc.)

- Finally if the hangar is a "membrane covered rigid steel frame"[1] and larger than a Group III, then it's a Group IV. (A foam system or closed-head sprinkler system is required.) This relatively new type of hangar construction is becoming more popular.

An owner may be interested in considering construction options that allow the facility to be classified at a lower protection level. In some cases, there may be compromises that afford substantial cost savings. Therefore, it's useful to know where the lines are drawn.

General requirements for construction and passive fire protection for both Group I and Group II hangars are found in Chapter 5. An abbreviated summary of the main requirements are:

- Construction must be non-combustible.
- Egress must meet NFPA 101, *The Life Safety Code*.
- For hangar fire areas to be considered (calculated) separately, 3-hour walls are needed between aircraft bays. Otherwise, multiple bays are considered as one area with larger water and foam demands.
- Shops and office areas must be separated from the aircraft bay by 1-hour rated walls.
- Building columns in aircraft bays must have 2-hour protection or the columns must be sprinklered.
- Hangar door power must be connected ahead of the building disconnect and must be operable in an emergency.
- Trench drains are required and must have the capacity to carry away the full design fire flow rate of the fire suppression systems.

- Any pits or tunnels in the hangar floors must be mechanically ventilated, drained, and treated as Class 1, Division 1 hazardous areas per the *National Electrical Code*.
- For Group I hangars only: draft curtains must be provided, enclosing projected floor areas of 7,500 ft² (700 m²) or less. These draft curtains do not define sprinkler zones and are not needed in Group II hangars.
- For Group I hangars, fire suppression requirements are found in Chapter 6 and in Chapter 7 for Group II hangars. The main differences between Group I and Group II hangars are:

1. When closed-head sprinkler systems are chosen, the Group I design criteria is 0.17 gpm/ft² (7 mm/min) over 15,000 ft² (1,400 m²), while Group II systems use the same density but with only a 5,000 ft² (460 m²) design area.
2. Water flow duration times are approximately 50% longer for Group I hangar systems than for those of Group II.
3. Draft curtains are not required in Group II hangars.

GROUP I CHOICES

Since the options with closed-head sprinklers plus low-level foam systems became available, foam-water deluge sprinklers are seen less often. This is particularly true when there are large aircraft with wing areas of more than 3,000 ft² (280 m²), which invokes the need to add supplemental foam systems. It's usually more economical to provide a larger low-level foam system instead of a supplemental foam system because the deluge system can be eliminated in favor of closed head sprinklers with a design area of 15,000 ft² (1,400 m²). Going through the exercise of estimating these demands bears this out.

High-expansion foam usually leads to lower water demands than with other options, sometimes making it an attractive choice. If high-expansion foam is selected as a low-level system, NFPA 409 calls for the foam generators to utilize outside air. This means that the foam generators need to be ducted through the roof to intake hoods. Louvers and dampers will also be needed for relief air. U.S. Air Force and Army design criteria allow the use of inside air, which simplifies matters considerably. Some AHJs may be willing to consider the military approach of using inside air.

COMMON SOURCES OF CONFUSION

Low-level vs. supplemental systems is perhaps the single greatest area of confusion in the standard. Supplemental systems are only provided in conjunction with foam-water deluge sprinkler systems. Supplemental systems need to cover only the area beneath the aircraft, while low-level systems must be calculated for the entire hangar floor area. The design, objectives and testing requirements for each are different.

High-expansion foam is often used as a low-level system, although the foam generators are usually installed up high, not close to the floor. Low-level systems are so named because their purpose is to cover the floor.

NFPA 409 provides a method for calculating the application rate of high-expansion foam. This method does not call for maintaining a submergence volume, because this is a local application approach, rather than a total flooding approach. The high-expansion foam is intended to act in a 2-dimensional manner. Therefore, it does not matter if the hangar doors are open or closed during foam discharge.

While the capacities of the water supply and foam system must be designed for complete coverage of the hangar floor, that does not mean they must all be activated simultaneously. The systems can and should be zoned in order to be discharged in response to heat detection on a zone-by-zone basis. Should the maximum number of zones be needed, the capacity must be available.

Redundancy is specified in different ways for water storage, for fire pumps and for foam supply.

- **Water Storage:** Should stored water be necessary, a divided supply is required. The idea is for half the water to be available if one tank is down for repair. It does not mean the water storage quantity is to be doubled. If 200,000 gallons (900 m^3) are needed to provide 45 minutes of flow duration, a pair of 100,000 gallon (450 m^3) tanks should be provided. They should be piped to be used at the same time.
- **Fire Pumps:** Should fire pumps be necessary (as they frequently are), the number and size of the fire pumps needed should be determined, and one additional pump of the same capacity should be provided. The requirement is for full pumping capacity with one pump out of service. Redundant jockey pumps are not required. Suction pipe sizing need not consider the redundant fire pump.
- **Foam Concentrate Pumps:** If foam pumps are being used, they are treated in the same manner as fire pumps as far as redundancy is concerned. The schematic piping diagrams in the annex of NFPA 11 do not show all required components, and they do not show how multiple pumps are to be connected.
- **Foam Tanks:** The requirement is for a "connected reserve" tank. The primary tank is to have full capacity for the 10-minute duration in the case of low-expansion foam, or 12 minutes in the case of high-expansion foam.

The connected reserve tank is to be of the same size as the primary tank. Its purpose is to be readily available after an event so the system may be put back into service quickly. As such, it should be connected so that manual operation of valves is needed to utilize its contents. This is true for both pressurized diaphragm tanks and atmospheric pressure tanks.

NFPA 409 is a prescriptive standard. If one wants to vary from its methods, NFPA 409, like most standards, allows for equivalencies or new technologies as long as the level of protection is not lowered. The authorities having jurisdiction have considerable discretion in this area if they choose to exercise it. Alternatives may be considered if one can provide analysis with enough rigor to satisfy the AHJ that a proposed alternative provides an equivalent level of protection.

Michael Aaron is with Rolf Jensen & Associates.

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AIRCRAFT FIRE SAFETY IMPROVEMENTS (2000-2010)

By Constantine Sarkos

Fire safety is an overriding concern in the design and operation of a commercial airliner, primarily because of the potential large loss of life in a single accident. Therefore, the Federal Aviation Administration (FAA) has maintained an extensive R&D program to improve aircraft fire safety. The research is driven by accidents, new airplane designs and new technology.

A previous article in *Fire Protection Engineering* summarized 20 years of R&D to improve aircraft fire safety and the airliner fire safety improvements derived from this research.[1] Research conducted in the last decade has produced additional aircraft fire safety improvements.[2]

Figure 1. Hidden In-Flight Fire Incident Involving Thermal Acoustic Insulation

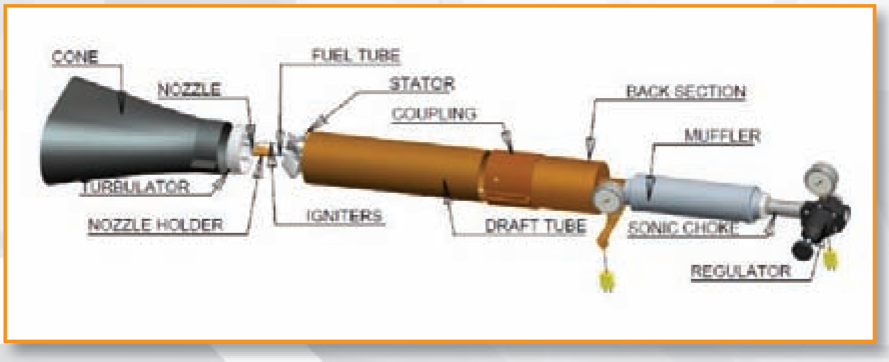

Figure 2. FAA Next Generation Burner for Insulation Fuel Fire Burn-through Resistance Evaluation

This article summarizes major improvements implemented over the last decade for each research driver, focusing on thermal acoustic insulation, fuel tank explosions, composite aircraft, and lithium-ion batteries.

THERMAL ACOUSTIC INSULATION FLAMMABILITY

Insulation blankets comprised of fiberglass batting, encapsulated within a plastic film, line the entire aircraft fuselage shell to attenuate noise and provide thermal insulation for passenger comfort. During a hidden, in-flight fire, the fire resistance of the insulation is important because it is often the first item ignited and the predominant hidden material (Figure 1). Tests showed that the FAA-required, vertical, Bunsen burner flammability test produced marginal pass/fail results for the insulation film on the fatal MD-11 in-flight fire aircraft, a metalized polyethyleneteraphalate (PET).[3]

Also, insulation may be a beneficial factor during a post-crash fire if modified to act as a barrier against fire penetration through the fuselage by an external fuel fire. Delaying fuselage fire penetration gives passengers more time to escape. Full-scale tests showed that improved insulation materials and barriers would substantially delay fire penetration.[4]

In-Flight Fire Ignition Resistance

To examine the behavior of different types of insulation blankets, a series of large-scale fire tests was conducted in an open-ended mock-up of the attic area above the passenger cabin ceiling. In a confined attic space, ignition and flame propagation may occur because of radiant heat feedback and containment of melted film near the ignition source. In general, when subjected to a relatively severe ignition source, the PET films were the most flammable, but more fire-resistant films prevented flame propagation, including polyvinyl fluoride (PVF) and polyimide (PI).[5]

The next step was to develop an improved flammability test method with pass/fail criteria that would identify materials capable of resisting a severe ignition source. It was found that the radiant panel test standard for flooring materials[6] gave a good correlation with the large-scale fire test data. The criterion adopted was, essentially, that the specimen did not ignite, which is specified by not allowing any flaming beyond a 2-inch (50 mm) length from the point of flame application, and no continued flaming after removal of the pilot flame.

Electrical arc testing was an important part of the insulation hazard assessment due to the reported incidents involving flame spread on thermal/acoustical insulation blankets caused by electrical arcing. The tests showed that the metallized PET blankets consistently ignited with significant flame spread. In contrast, the polyimide and PVF blankets did not ignite, and the plain PET blankets exhibited minimal flame spread and self-extinguished.[7]

These findings prompted the FAA to issue Airworthiness Directives (ADs), requiring the replacement of metallized PET insulation in more than 700 aircraft.[8,9] The FAA also improved the Federal Aviation Regulations by requiring the radiant panel test method and criteria for insulation, replacing the Bunsen burner test method.[10]

After Sept. 2, 2005, any large transport aircraft manufactured in the United States was required to be lined with insulation compliant with the radiant panel test criteria. In addition, a radiant panel test methodology was developed to evaluate installation methods found to contribute significantly to insulation flammability.[11] Lastly, another AD was adopted to replace insulation blankets made of PET called AN-26 because of its vulnerability to ignition and fire spread from an electrical arc.[12]

Post-crash Fire Burn-through Resistance

A new test method was developed to measure the penetration or burn-through resistance of thermal acoustic insulation during a post-crash fuel fire.[13] Tests indicated that a variety of materials could provide the needed four minutes of burn-through protection, demonstrating the feasibility of this criterion. The four-minute value was based on an analysis of past accidents, which showed that evacuation times varied considerably—depending on many factors—but rarely exceeded five minutes, and accounting for the time to melt the aluminum fuselage. A replacement burner dubbed the "NexGen Burner" was also developed; it was made from readily available materials because the previous burner specified by FAA was no longer manufactured (Figure 2).[14]

FAA adopted a final rule that contained a new requirement for burn-through resistance insulation installed in commercial transport aircraft. Newly manufactured aircraft were required to have burn-through resistant insulation after Sept. 2, 2009.[15,16] In addition, an advisory circular was developed and published that provides guidance on the "installation details and

techniques that have been found to be acceptable to realize the full potential of materials having satisfactory fire-resistant properties."[17]

FUEL TANK EXPLOSION PROTECTION

A major research program was conducted by the FAA to protect against fuel tank explosions. It was largely driven by TWA 800 and two other fatal center wing tank explosions; *viz., 737, Manila, 1990 and 737, Bangkok, 2001*. The three accidents had striking similarities, but in all three cases the ignition source that triggered the explosion could not be determined.

Fuel Tank Inerting

FAA developed a practical and effective fuel tank inerting system, or On-Board Inert Gas Generating System (OBIGGS), capable of providing protection throughout the entire aircraft flight and ground profile. Unlike the heavier and less reliable military OBIGGS in the C-5A and C-17, the FAA-developed system is simple, lightweight and practical, utilizing available engine bleed air to continuously provide nitrogen-enriched air (NEA) to inert the center wing fuel tank (Figure 3).

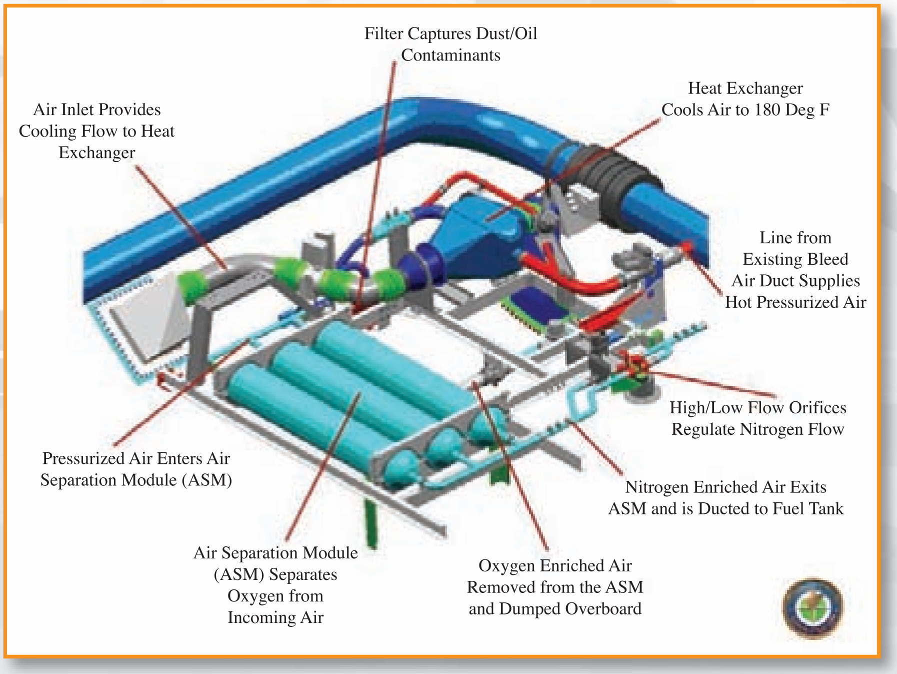

Figure 3. Schematic of On-Board Inert Gas Generation System (OBIGGS)

The NEA is generated by the air separation modules, which contain hollow fiber membranes capable of separating nitrogen from oxygen in air. However, the critical feature of the FAA OBIGGS

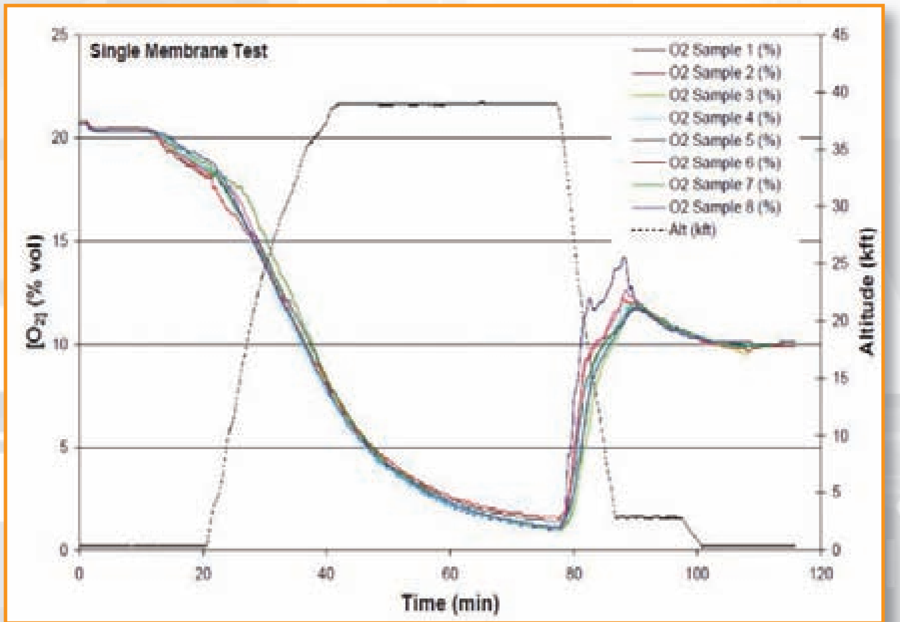

Figure 4. A320 Oxygen Concentration Histories in Center Wing

was a dual-flow capability – low flow rate/high NEA purity during ground, ascent and cruise conditions and high-flow rate/low NEA purity compatible at the required inerting concentration during descent. With a simple design, and few moving parts, the FAA OBIGGS was reliable, relatively lightweight (about 160 pounds [72 kg]) and inexpensive ($150,000-$200,000) for a 747.

Aircraft flight tests were needed to corroborate the predicted performance of the OBIGGS and demonstrate its operational capability. The OBIGGS was initially tested in an Airbus A320[18] and later in the NASA B747 shuttle carrying airplane (SCA).[19] A unique instrument developed by FAA, called an on-board oxygen analysis system (OBOAS), measured the oxygen concentration at eight CWT locations.[20]

The results from one A320 test are shown in Figure 4. During ground, ascent and cruise, at the low-flow NEA setting, the oxygen concentration continuously decreased. At the onset of descent, the NEA flow rate was set at the high setting. The oxygen concentration increased as air rushed into the CWT during descent; however, the higher NEA flow rate prevented the oxygen concentration from exceeding the limiting oxygen concentration (LOC) of 12%.

Limiting Oxygen Concentration

The Limiting Oxygen Concentration (LOC) is the minimum concentration of oxygen in air that will allow fuel vapor combustion. FAA tests in a simulated fuel tank determined that the LOC was 12% at sea level to 10,000 feet (3 km), and increased approximately linearly thereafter to 14.5% at 40,000 feet

Figure 5. Burn-through Resistance of Composite Fuselage Skin Subjected to a Jet Fuel Fire for 5 Minutes

(12 km).[21, 22] The 12% value is fairly consistent with LOC values in the literature for the hydrocarbon constituents of jet fuel. It was an enabling factor in the development of a simple and cost-effective OBIGGS for commercial transport aircraft.

FAA Regulation to Prevent Fuel Tank Explosions

On July 21, 2008, FAA issued a final rule titled "Reduction of Fuel Tank Flammability in Transport Category Airplanes,"[23] which was made possible by the FAA OBIGGS development. It was estimated that the final rule would prevent one or two catastrophic fuel tank explosions over a 35-year period. Five thousand aircraft in the U.S. fleet would be impacted by the rule at a compliance cost of more than $1 billion.

COMPOSITE AIRCRAFT FIRE SAFETY

The new Boeing 787 is constructed of composite fuselage and wings in order to gain significant operational cost savings from lower weight, corrosion resistance and less maintenance due to increased fatigue strength. The composite material is comprised of multiple, alternately directed layers of epoxy-impregnated, continuous graphite fibers. Fire safety was a concern because epoxy resins are flammable.

During FAA certification of the B787, Boeing was required to demonstrate that the level of fire safety in the B787 was equivalent to a conventional (aluminum) aircraft. FAA conducted research and testing to characterize and understand the fire behavior of this type of composite structure and to support the certification process.

When heated, the epoxy resin vaporizes and burns, leaving behind an inert insulation layer of graphite fibers. This causes a reduction in internal heating as each subsequent ply of epoxy-graphite burns, and a reduction in the burning rate with time. Overall, the composite displayed superior fire burn-through resistance and relatively good fire resistance.[24]

Boeing proposed that the burn-through resistance of the B787 composite fuselage provided an equivalent level of safety with the insulation burn-through resistance regulation. To evaluate this proposal, which would negate the need for burn-through-resistant insulation in the B787, FAA developed a small-scale test to expose composite materials to a simulated post-crash fire and analyze gas emissions that could migrate into the cabin and impact survivability.[25] Full-scale, post-crash fire tests helped develop scaling factors to use in conjunction with the small-scale test to predict cabin gas concentration levels.[26] The full-scale fire tests again exhibited the superior burn-through resistance and low gas emissions of the carbon fiber composite when subjected to a severe jet fuel fire (Figure 5).

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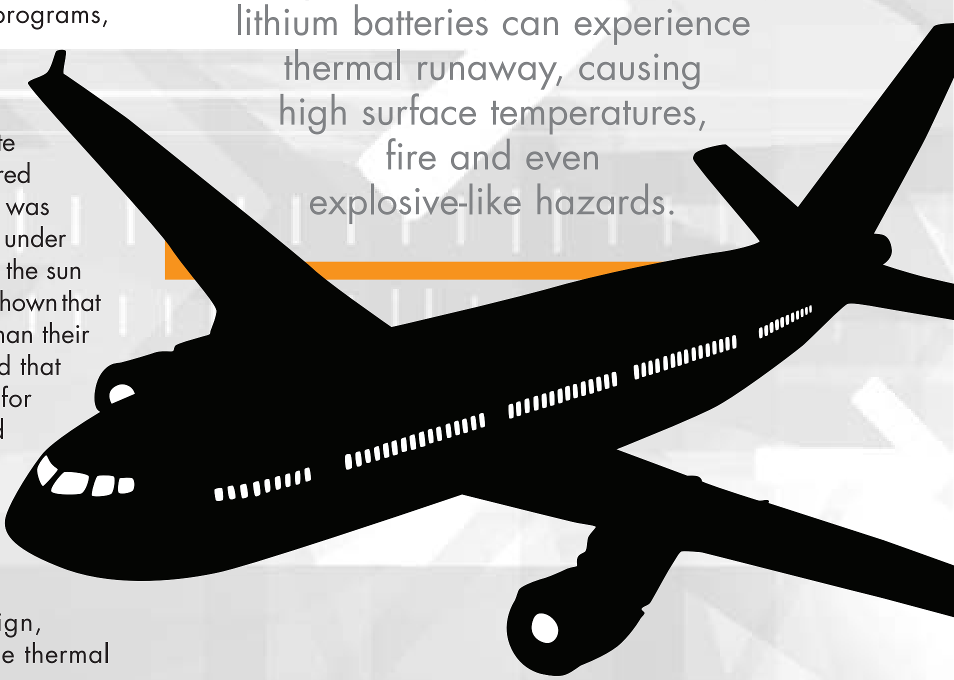
Boeing also had to demonstrate that the B787 provided protection against a hidden in-flight fire. Intermediate-scale tests were required similar to those performed by FAA during development of the improved fire test method for thermal acoustic insulation. To obviate the need for these intermediate-scale tests in future certification programs, FAA developed a small-scale fire test method to measure the in-flight fire resistance of composite fuselage structure.

The flammability of fuel vapor inside a composite wing fuel tank was examined by FAA and compared with aluminum tanks.[27] Fuel vapor concentration was measured in wing tanks made of both materials, under conditions simulating heating on the ground from the sun and in-flight air flow cooling in a wind tunnel. It was shown that composite wing fuel tanks are more flammable than their aluminum counterparts during solar heating, and that painted surfaces greatly impacted the heat-up for both types of tanks. However, rapid cooling and reduction in flammable vapors was observed in both tanks under simulated flight conditions.

LITHIUM BATTERY FIRE HAZARDS

Due to their high energy density and design, malfunctioning lithium batteries can experience thermal

Due to their high energy density and design, malfunctioning lithium batteries can experience thermal runaway, causing high surface temperatures, fire and even explosive-like hazards.



Bulk Load Configuration Before Testing

Bulk Load Configuration After Testing

Figure 6. Thermal Runaway Propagation in Bulk-loaded Lithium Batteries.

runaway, causing high surface temperatures, fire and even explosive-like hazards.

The incident that highlighted the dangers of lithium battery fires in aircraft occurred at Los Angeles International Airport in 1999. Two off-loaded pallets of lithium batteries from an incoming flight caught fire. It took airport firefighters about 25 minutes to extinguish the difficult fire. Since 1991, more than 44 air-transport-related battery fire incidents have occurred, mostly involving freighter aircraft.[28]

FAA conducted tests on the two main types of lithium batteries: primary or metal (non-rechargeable)[29] and ion (rechargeable).[30] With either type of battery, thermal runaway of a single battery in a typical cardboard shipping box resulted in thermal runaway and ignition of the remaining batteries in the box (Figure 6).

However, the metal batteries were found to be far more hazardous. A metal battery fire involves burning lithium, which can be ejected in a molten state. It produces heavy smoke and overpressures, which would breach the cargo compartment liner, raising the likelihood of fire and smoke spreading to the cabin and cockpit.

Halon 1301, the fire extinguishing agent in passenger aircraft cargo compartment fire suppression systems, has no observable effect on a metal battery fire.[29] Conversely, when an ion battery overheats, the flammable electrolyte vents and ignites in the presence of an ignition source. However, Halon 1301 extinguishes the electrolyte fire and prevents re-ignition at a concentration of 3%, which is the minimum concentration required to be maintained by a cargo compartment fire suppression system.[30] Because of the inability of a halon fire suppression system to control a metal battery fire, an Interim Final Rule was issued that prohibits the bulk shipment of metal lithium batteries on passenger-carrying aircraft.[31]

FAA has also conducted tests with shipping containers to ascertain their capabilities for withstanding a lithium battery fire.[32] Typical cardboard shipping boxes will burn and be consumed by a shipment of either type of lithium batteries experiencing thermal runaway.

Available robust shipping containers, such as metal pails and drums recommended by the International Civil Aviation Organization (ICAO), were ineffective against metal battery fires because of the build-up of pressure, which caused the sealed lid to fail and expel the burning batteries. However,

Available robust shipping containers, such as metal pails and drums recommended by the International Civil Aviation Organization (ICAO), were ineffective against metal battery fires because of the build-up of pressure, which caused the sealed lid to fail and expel the burning batteries.

burning ion batteries were contained in a cardboard box designed to safely ship oxygen generators.[33]

A preliminary performance standard for a shipping container for lithium-ion batteries was developed, which was partly based on the oxygen shipment standard. The documented findings[32] were the primary source of information contained in the FAA Safety Alert for Operators (SAFO) titled, "Risks in Transporting Lithium Batteries in Cargo by Aircraft."[34] FAA research strives to better understand and safeguard against the fire hazards of lithium battery cargo shipments.

Constantine Sarkos is with the Federal Aviation Administration.

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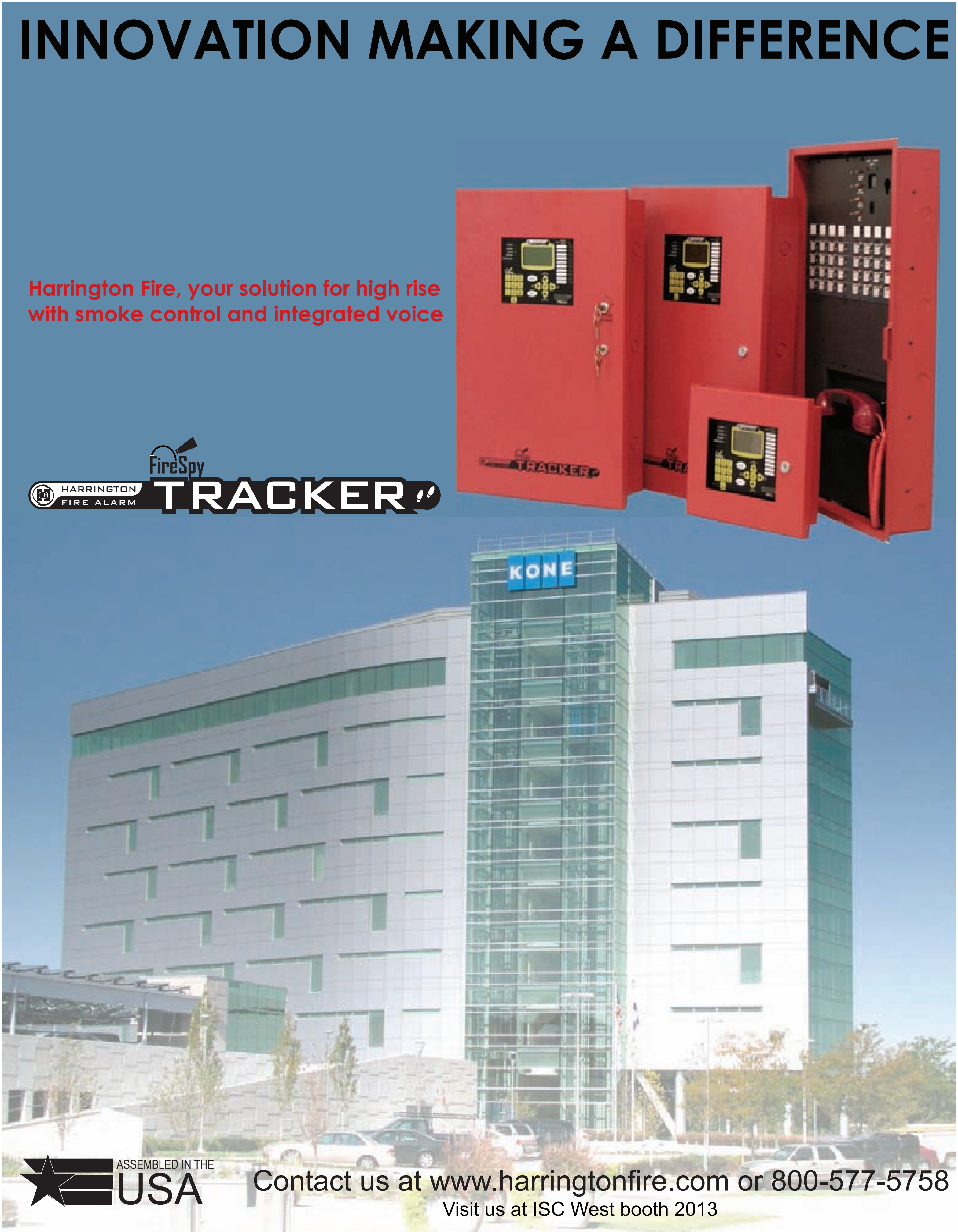
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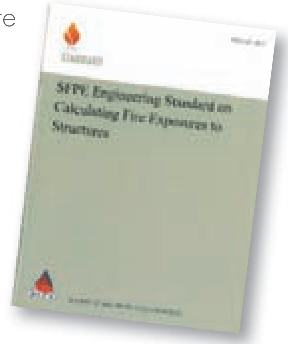

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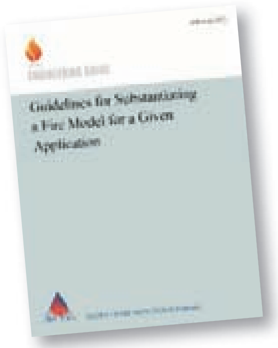

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BRAINTEASER [Problem/Solution]

Problem

A motionless ice skater who weighs 50 kg throws a ball that weighs 0.25 kg forward at a velocity of 50 m/s. If the friction between the ice skater and the ice is negligible, at what velocity will the ice skater move?

Solution to Last Issue's Brainteaser

Two cars travelling in the same direction leave from the same location at the same time. One car travels at a speed of 100 km/h, while the other car travels at a speed of 120 km/h. How long will it be before the faster car is 15 minutes ahead of the slower car?

For the faster car to be 15 minutes ahead of the slower car, it must be $\frac{100\text{ km}}{\text{h}} \times \frac{\text{h}}{60\text{ min}} \times 15\text{ min} = 25\text{ km}$ ahead.

The distance from the starting point as a function of time for the two cars can be expressed as follows:

$$D_1 = 100\text{ km/h} \times t$$
$$D_2 = 120\text{ km/h} \times t$$

Where t is the elapsed time.

Since the faster car is 25 km ahead of the slower car, these can be combined as follows:

$$100\text{ km/h} \times t + 25\text{ km} = 120\text{ km/h} \times t$$

Solving for t: $t = 1.25$ hours.

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April 17	Denver, CO		

Morning session runs from 8:00 a.m. – 12:00 p.m.

Optional Lunch Session available! We invite you to stay for lunch while we provide a brief 20 minute overview of the latest in touch-screen technology. The S3 Series, Smart + Simple Small Addressable Fire Alarm System is the first in its class to offer an intuitive, user-friendly, touch-screen interface, making fire alarm panel operation and system maintenance a breeze.

To register today online or for further information visit our website at www.gamewell-fci.com or contact Melanie Cobb at (203) 871-5206 or via email at melanie.cobb@honeywell.com

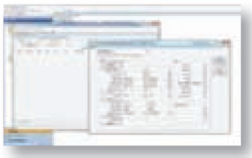
Gamewell-FCI • 12 Clintonville Road, Northford, CT 06472 • www.gamewell-fci.com

New Rigid Coupling

Victaulic introduces the FireLock EZ® Style 009N Rigid Coupling. The improved design is easier to install than the Style 009H Rigid Coupling, reducing installation efforts by 50 percent and improving impact wrench battery efficiency by 100 percent. With an optimized housing design, it has no loose parts and ships to the jobsite ready to install. As Style 009H inventory reduces, the Style 009N Rigid Coupling will become the standard Victaulic fire protection solution in pipe sizes 1 ¼ to 4 in. up to 365 psi.

www.victaulic.com
—Victaulic

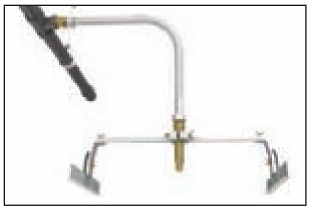
Enterprise Resource Planning



Potter Electric Signal Co. has implemented a new ERP software system called Epicor. This enterprise resource planning platform uses SOA or Service Oriented Architecture as "an approach to developing enterprise software applications in such a way that software processes are broken down into services which are then made available and discoverable on a network." This feature alone will save Potter time and money with future customizations and upgrades.

www.pottersignal.com
—Potter Electric Signal Co., LLC

Flexible Sprinkler Connections



Viking has introduced a new cULus Listed flexible sprinkler connection. The Model FSC-25U is a complete assembly that provides a faster, easier installation of sprinklers in suspended tile ceilings, when compared to hard-piped sprinkler drops. Viking's Model FSC-25U also offers generous amounts of lateral and vertical adjustment for precisely locating sprinklers in "center-of-tile" installations. It features a redesigned, factory-assembled attachment bracket that is ready to install out of the box, without additional loose parts.

www.vikinggroup.com
—Viking Corp.

Compressed Air Foam Systems

Primary Flow Signal, Inc.'s new ACAF® Systems-PFS Fire Suppression Group, LLC, focuses on compressed air foam (CAF) systems both self-contained and fixed water supply, using its unique patented CAF mixing chamber and nozzles. The new technologies provide a state of the art delivery system with highly enhanced fire extinguishing performance characteristics for the foam suppression agent.

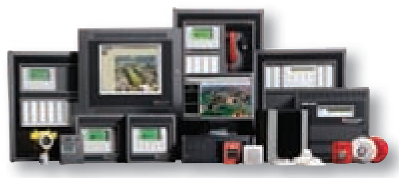
www.acafsystems.net
—ACAF® Systems-PFS-Fire Suppression Group, LLC

Combination Smoke/CO Alarm

Gentex has released a combination photoelectric smoke and CO alarm designed with two sets of Form A/Form C relay contacts that activate independently for smoke and CO events. The GN-503FF is primarily used for applications where the need to distinguish between smoke and CO events is imperative. The GN-503FF is a 120VAC hard wired alarm with 9VDC alkaline battery back-up in the event building power is lost.

www.gentex.com
—Gentex Corp.

Expanded Line of Amplifiers



NOTIFIER has expanded its line of amplifiers to provide more flexible options for powering its fire alarm and emergency communications systems' audio announcements. The addition of new 100-watt and 125-watt amplifiers enables NOTIFIER systems to provide better audio solutions for larger buildings, outdoor areas, and industrial applications with high levels of ambient noise.

www.notifier.com
—NOTIFIER

Photoelectric Detector

The Acclimate 2251TMB photoelectric detector includes thermal detection at 135°F. It uses advanced onboard software to combine the signals from the photo and thermal elements to create a true multi-criteria detector that responds quickly to real fires while rejecting nuisance alarms. Using advanced software, Acclimate continuously samples the air in the environment and adjusts its detection parameters and alarm threshold accordingly. It does this automatically without user intervention.

www.systemsensor.com
—System Sensor

Pendent Sprinkler Enhancements

TYCO has announced new enhancements to the existing UL Listing of the TYCO Model ESFR-25 pendent sprinkler in storage occupancies. The new Model ESFR-25 sprinkler provides advanced, cost-effective solutions for storage applications with up to 48-ft ceiling heights, offering a low minimum operating pressure. Higher ceiling-only protection eliminates the need for in-rack sprinklers for protection of class I through cartoned unexpanded group A plastics in various storage arrangements.

www.tycofsbp.com
—Tyco Fire Protection Products

Analog Addressable Fire Panel

The FPA-1000-V2 Analog Addressable Fire Panel now includes networking capabilities. This new feature allows installers to connect multiple panels to monitor up to 2,000 addressable points in one system. The networkable panel is suitable for a wide range of environments, including retail centers, educational facilities and campuses, government sites, medical facilities, and more. The panel supports networking via wired Ethernet, fiber optic or two- conductor wire. Mixed wiring types on one module allow multiple connection methods in the same network.

www.boschsecurity.us
—Bosch Security Systems, Inc.

One-Fastener Solution

The One Hole Hanger & Restrainer, Figure 22L2, supports CPVC and IPS piping to concrete ceilings. It features flared edges to help protect plastic pipe, no compressive loading of the pipe, and is cULus listed as a hanger and restrainer per NFPA 13 requirements. The Figure 22L2 is designed to reduce installation time and allows for an easy, one-fastener attachment for CPVC and IPS systems to concrete ceilings. It is available in sizes ranging from ¾ to 2 in. and can support pipes vertically or horizontally for walls or ceilings.

www.cooperbline.com
—Cooper B-Line

Clean Agent Calculator App

Fike Corp. announces its new Clean Agent Calculator Application. Designed to be used predominately through mobile devices, this tool quickly and easily estimates volume of agent, and quantity of containers and nozzles needed for a given fire suppression application. In addition, the app provides a side-by-side comparison of Fike's premier fire suppression products ECARO-25®, DuPont™ FM-200® and ProInert®, in order to determine which agent best suits the situation.

www.fikeCAcalc.com
—Fike

Aerosol Suppression Technology

Gamewell-FCI's Conventional Agent Release Control Panel (Flex GR506R) provides powerful fire protection while simultaneously controlling the release of one or two fire suppression agents. The Flex GR506R panel is compatible with nearly 40 releasing control devices for as many as 12 sprinkler and fire suppression agents, and is currently one of only two UL-Listed releasing systems for the new aerosol suppression agents growing in popularity since the NFPA's introduction of its 2010 Standard for Fixed Aerosol Fire-Extinguishing Systems.

www.gamewell-fci.com
—Gamewell-FCI

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FIRE PROTECTION Engineering

Fire Protection Engineering (ISSN 1524-900X) is published quarterly by the Society of Fire Protection Engineers (SFPE). The mission of *Fire Protection Engineering* is to advance the practice of fire protection engineering and to raise its visibility by providing information to fire protection engineers and allied professionals. The opinions and positions stated are the authors' and do not necessarily reflect those of SFPE.

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Kidde Fire Systems

ECS Clean Agent Suppression Systems

Proven, Effective and Reliable...

Fire Protection that's Engineered Clean and Safe

Equipment and processes are vital to the success of all commercial endeavors. Consider the ramifications of a fire in these critical areas. Smoke or soot contamination, water damage, destroyed equipment and idle process lines could force your business offline and out of competition. Kidde's ECS™ Clean Agent Suppression Systems extinguish a fire in seconds, safeguarding your people and property.

With more than 90 years in the industry, Kidde Fire Systems is the leader in the Clean Agent special hazards market. Kidde's quality products and services can be found globally with distributors located in major cities around the world and a network, of more than 300, throughout the United States and Canada.

Kidde ECS Systems Feature:

Rapid-Response. In seconds — not minutes, the ECS System discharges Clean Agent suppressant into the hazard area providing the fastest fire protection available. This results in less damage, fewer repair costs and reduced downtime.

Damage-Free. Clean Agent suppressants allow virtually immediate return to "business as usual" without the interruption of a costly clean-up and the expense of damage to assets from suppressant residue.

People-Safe. Our ECS System is safe for use in occupied areas. Clean Agents do not impair breathing or obscure vision in an emergency situation — providing an added measure of safety for personnel.

The Right Fire Protection Company. The Kidde integrated approach offers a complete fire protection system that is designed, manufactured, installed and serviced by one company. From refineries to commercial kitchens... it's likely that Kidde Fire Systems is on the job.

www.kiddefiresystems.com

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