FIRE DETECTION SYSTEM AND SPURIOUS (FALSE) FIRE WARNING OF THE AIRCRAFT - AN OVERVIEW

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Abstract

New fire detection technologies are under evaluation for better aircraft safety and risk managements. The goal is to reduce the false alarm rate and to improve safety and reliability features of an aircraft. In this paper, an overview of different types of fire detection system of aircraft is given. Technology currently used for fire detection and protection are discussed. Also analysis and the probable causes of false fire warning of the aircraft are listed along with its future scope of fire protection system for aircraft are discussed.

Keywords: Fire Detection System, Fire Alarm, Aircraft Safety, False Alarm

Introduction

A fire protection system in an aircraft includes passive and active fire protection. Passive fire protection is realized by using fire proof or inflammable materials in all areas of the aircraft including lining, cables, interior etc. In this paper, the active fire protection system is considered which consists of unit and continuous loop type fire detectors. Also analysis of spurious fire warning on aircraft is discussed.

Several aircraft areas are equipped with fire detection instruments [1-4]. These are the cargo compartments, the electronic compartments and the lavatories. The most important and critical area is the Engine nacelle and LG well, which is inaccessible during flight.

Since fire is one of the most dangerous threats to an aircraft, the potential fire zones of modern multiengine aircraft are protected by a fixed fire protection system. A fire zone is an area, or region, of an aircraft designed by the manufacturer to require fire detection and/or fire extinguishing equipment and a high degree of inherent fire resistance [5-10].

A complete fire protection system on modern aircraft and on many older aircraft includes a fire detection system and a fire extinguishing system.

Historical Prospective

- In 1658 New York’s finest deployed men to walk around the streets looking for fires, with buckets on ladders and ringing bells to warn the community. In the 1800s, fire alarms became a little more advanced with the placement of bell towers around cities to warn off people of a fire (Source: www.ryanfp.com/fire-alarm-history).

- The fire alarm progressed in 1852, where it reached a new level of technology. Using the telegraph system, two alarm boxes with a telegraphic key were used to report neighbourhood fires. One man would crank the handle that was attached to the box, releasing the key to send out a message to the central alarm station. The telegrapher at the central station would then send out the address of the location to the fire department (Source: www.ryanfp.com/fire-alarm-history).

- The first automatic electric fire alarm was patented in 1890 by Francis Robbins Upton and Fernando dibbe (Source: the smoke detector.umwblog.org/antece-dents-evolution).

- Thermal detectors are the oldest type of automatic detection device, having origin in the mid 1800’s, with several styles still in production today.

Prior to the middle of the 20th century, few office buildings and no residences were protected by automatic fire detection systems of any type.

In 1939 Swiss physicist Dr. Ernst Meili devised an ionisation chamber device capable of detecting combustible gases (Source: Wikipedia/fire alarm/ history).

The invention of the cold cathode tube in the 1940s allowed Meili to produce the forerunner of the modern ionisation smoke detector (Source: Wikipedia/fire alarm/ history).

Smoke detectors are a much newer technology, having gained wide usage during the 1970’s and 1980’s in residential and life safety applications.

In new trend gas filled tube type fire detectors are used for fire detection of aircraft engine compartment [11-15].

Different sensor outputs are efficiently used by intelligent softcomputing techniques to accurately detect the fire and automatic initiation of fire warning / extinguishing system [16-17].

The Principle of Fire Detection

Unit/Spot Fire Detection

Two basic type of unit fire detectors used in the aircraft are thermocouple and a bi-metallic switch. A thermocouple consists of two dissimilar materials which will generate a small voltage when its heated as shown in Fig.1. They are also used in Exhaust Gas Temperature (EGT).

The bi-metallic switch as shown in Fig.2 detects a temperature change as each of the two dissimilar materials have a different expansion thereby deforming the metal arm and contacting a switch, thereby opening or closing it depending on the type of switch that is used.

Continuous-Loop Detection System

A continuous-loop detector or sensing system permits more complete coverage of a fire hazard area than any type of spot-type temperature detectors. Continuous-loop systems are versions of the thermal switch system. They are overheat systems, heat-sensitive units that complete electrical circuits at a certain temperature. There is no rate-of-heat-rise sensitivity in a continuous-loop system. Two widely used continuous-loop systems are the Kidde and the Fenwal systems.

The following is a list of detection methods most commonly used in turbine engine aircraft fire protection systems.

- Rate-of-temperature-rise detectors.
- Radiation sensing detectors.
- Smoke detectors.
- Overheat detectors.
- Carbon monoxide detectors.
- Observation of crew or passengers.

The different types of detectors mentioned above have different principles, speed, accuracy and reliability. Based on the safety requirement(s) one or more types of fire detectors are used in aircraft fire protection system.

Important Features of Ideal Fire Detection System

An ideal fire detection system will include the following features for the aircraft.

- A system which will not cause false warnings under any flight or ground operating conditions.
- Rapid indication of a fire and accurate location of the fire.
- Accurate indication that a fire is extinguished.
- Indication that a fire has re-ignited.
- Continuous indication for duration of a fire.
- The means for electrically testing the integration of detectors from the aircraft cockpit.
- Detectors which resist exposure to oil, water, vibration, extreme temperatures, maintenance handling.
- Detectors which are light in weight and easily adaptable to any mounting position.
- Detector circuitry which operates directly from the aircraft power system without inverters.
- Less power consumption requirements when not indicating a fire.
- Each detection system should actuate a cockpit light indicating the location of the fire and an audible alarm system.
- A separate detection system for each engine.
Fire Protected Zones of the Aircraft

The fire detectors are installed on the following zones of the aircraft:

- Left Wing
- Left engine nacelle
- Right wing
- Right engine nacelle
- APU (Auxiliary Power Unit)
- Cargo compartment
- Avionics compartment

Fire Detection System Used in Aircraft

A fire detection system should signal the presence of a fire. Units of the system are installed in locations where there are greater possibilities of a fire. Three detector systems in common use, are the thermal switch, thermocouple, and the continuous loop.

Thermocouple System

A thermocouple depends on the rate of temperature rise and does not give a warning when an engine slowly overheats or a short circuit develops. The system consists of a relay box, warning lights, and thermocouples. The wiring system of these units may be divided into the following circuits:

- Detector circuit
- Alarm circuit, and
- Test circuit

These circuits are shown in Fig.3. The relay box contains two relays, the sensitive relay and the slave relay, and the thermal test unit.

In the engine compartment, there is a normal, gradual rise in temperature from engine operation; because it is gradual, both junctions heat at the same rate and no warning signal is given. If there is a fire, however, the hot junction heats more rapidly than the reference junction. The ensuing voltage causes a current to flow within the detector circuit. Any time the current is greater than 4 mA (0.004 ampere), the sensitive relay closes. This completes a circuit from the aircraft power system to the coil of the slave relay. The slave relay then closes and completes the circuit to the warning light to give a visual fire warning.

The total number of thermocouples used in individual detector circuits depends on the size of the fire zones and the total circuit resistance, which usually does not exceed 5 ohms.

Thermal Switch System

The thermal switches are heat sensitive units that complete electrical circuits at a certain temperature. They are connected in parallel with each other but in series with the indicator lights as shown in Fig.4. If the temperature rises above a set value in any one section of the circuit, the thermal switch closes, completing the light circuit to indicate a fire or overheat condition. No set number of thermal switches is required; the exact number is usually determined by the aircraft manufacturer.

Continuous-Loop Systems

Almost all transport aircraft exclusively uses continuous thermal sensing elements for engine and wheel fire protection. These systems offer superior detection performance and coverage, and they have the proven ruggedness to survive in the harsh environment of modern turbofan engines.

A continuous-loop detector or sensing system permits more complete coverage of a fire hazard area than any of the spot-type temperature detectors. Two widely used types of continuous-loop systems are the thermistor type detectors, such as the Kidde and the Fenwal systems, and the pneumatic pressure detector.

Fenwal System: The Fenwal system uses a slender Inconel tube packed with thermally sensitive eutectic salt and a nickel wire center conductor. Lengths of these sensing elements are connected in series to a control unit. The elements may be of equal or varying length and of the same or different temperature settings. The control unit, operating directly from the power source, impresses a small voltage on the sensing elements. When an overheat condition occurs at any point along the element length, the resistance of the eutectic salt within the sensing element drops sharply, causing current to flow between the outer sheath and the centre conductor. This current flow is sensed by the control unit, which produces a signal to actuate the output relay and activate the alarms.
Kidde System: In the Kidde continuous-loop system, two wires are imbedded in an inconel tube filled with a thermistor core material. Two electrical conductors go through the length of the core. One conductor has a ground connection to the tube, and the other conductor connects to the fire detection control unit. As the temperature of the core increases, electrical resistance to the ground decreases. The fire detection control unit monitors this resistance.

Pressure Type Sensor Responder Systems: Some smaller turboprop aircraft are outfitted with pneumatic single point detectors. The design of these detectors is based on the principles of gas laws. The sensing element consists of a closed, helium filled tube connected at one end to a responder assembly. As the element is heated, the gas pressure inside the tube increases until the alarm threshold is reached. At this point, an internal switch closes and reports an alarm to the cockpit. Continuous fault monitoring is included. This type of sensor is designed as a single-sensor detection system and does not require a control unit.

Fire Detection Control Unit and Workflow of Fire Detectors

The control unit for the simplest type of system (Fig.5) typically contains the necessary electronic resistance monitoring and alarm output circuits housed in a hermetically sealed aluminium case fitted with a mounting bracket and electrical connector. In the most advanced applications, the detection system circuitry controls all aircraft fire protection functions, including fire detection and extinguishing for engines, APUs, cargo bays as shown in Fig.6.

Analysis of Spurious Fire Warning of Aircraft

Classification Logic of Fire and False Fire Warning: Fire and false alarm events in operation were extracted from different data base and compiled as shown in Fig.7.

Attributed Factors of False Fire Warning of Aircraft: The physical conditions, identified sources and causes of events are shown in Table-1.

Case Studies

Fire Warning of UH-I Iriquois (an USA Army Aircraft): The UH-1 was evaluated for fire indications between fiscal years 1988 and 1992. During this period, the UH-1 had approximately 102 cases of fire indication. On further analysis, out of these, 102 cases of fire indications only 4 cases (3.9%) of actual fire were observed. It means 98 cases (96.1%) were false fire warning. The 98 cases of false fire warning and 4 cases of actual fire warning can be broken down as follows:

- 34 cases of fire warning activations 33.33%, which is explained in Table-2.
- 10 cases of Hot start 9.8%.
- 8 cases of Short circuit related to circuit-breaker switches or rheostats 7.8%.
- 5 cases of failed windshield-wiper motors 4.9%.
- 5 cases of Smoke through the heat ducts 4.9%.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Unit/Area Involved</th>
<th>No. of Cases</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control Box</td>
<td>4</td>
<td>14%</td>
</tr>
<tr>
<td>2</td>
<td>Poor Connection</td>
<td>7</td>
<td>18%</td>
</tr>
<tr>
<td>3</td>
<td>Short or System Grounded</td>
<td>3</td>
<td>9%</td>
</tr>
<tr>
<td>4</td>
<td>Sensor Wire Failure</td>
<td>15</td>
<td>42%</td>
</tr>
<tr>
<td>5</td>
<td>Unspecified</td>
<td>5</td>
<td>16%</td>
</tr>
</tbody>
</table>

Table-1 : Classification of Events (False Fire Warning)

<table>
<thead>
<tr>
<th>Physical Conditions</th>
<th>Identified Sources</th>
<th>Causes of Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft’s place and situations</td>
<td>Source (Engine or Wing of the aircraft)</td>
<td>System misbehaviour</td>
</tr>
<tr>
<td>Flight phase</td>
<td>Aerosol presence</td>
<td></td>
</tr>
<tr>
<td>Environment conditions</td>
<td>Leakage in the cable of ignition unit</td>
<td>Human error</td>
</tr>
<tr>
<td>Atmospheric condition</td>
<td>Propagation</td>
<td>Bad weather conditions</td>
</tr>
<tr>
<td>Hazards to aircraft</td>
<td>Non classification</td>
<td>Unknown events</td>
</tr>
</tbody>
</table>

Table-2 : 34-Cases of False Fire Warning of UH-I Aircraft
• 5 cases of Smoke in the transmission area from spilled oil or chaffing 4.9%.
• 7 cases of Failures (shorts) of instruments, inverters or relays 5.8%.
• 5 cases of Battery failures 4.9%.
• 5 cases of Unknown sources of electrical smoke 4.9%.
• 4 cases of actual fire warning (seen by the crew or ground crew) at or near the engine compartment 3.9%.

The 34 cases of false fire-warning activations of UH-I could be broken down as shown in Table-2.

**General Outcomes from the Analysis of Spurious Fire Warning:** The study of false fire warning (refer Fig.8) acquainted that in most of the cases, the conditions in the fire protected area at the time of the alarm were not exactly known by the pilots or the crew members; therefore false alarm events were often considered unexplainable or attributed to a system malfunction whereas a better knowledge of these conditions would have led to a different classification.

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

**Probable Causes of Spurious Fire Warning in Aircraft**

• Intermittent alarms are most often caused by an intermittent short in the detector system wiring. Such shorts may be caused by a loose wire that occasionally touches a nearby terminal, a frayed wire brushing against a structure.
• A sensing element rubbing against a structural member may cause a false fire alarm signal.
• Kinks and sharp bends in the sensing element can cause an internal wire to short intermittently to the outer tubing.
• Moisture in the detection system some time causes a false fire alarm.
• Malfunctioning of electronic components of fire control unit.
• A transient voltage or radio interference may be reason for false fire signal.
• A poor installation of fire detectors in the aircraft.
• Poor insulation of electrical wires connected to detectors may cause false fire warning hence IR test of fire detectors wiring to be performed at regular servicing of the aircraft.

**Reliability of Fire Detection System**

• The explanation of actual fire alarm events is tricky because most of the time, the parameters recorded at the time of the event do not allow to determine the condition for which the alarms were triggered and can even lead to wrong conclusions.
• However this study has acquainted us that the percentage of correct alarming system is very less in this case study only 2.3%. The recommendation is, with proper maintenance of fire detectors, control box and concern electrical wiring the reliability of fire protection system can be improved.
• False alarm sources are also diversified, in some cases the corresponding single physical parameters may be very close to those that characterise the start of a fire. The recommendation is use a suitable and advanced fire detectors technology for aircraft.
• Under these conditions, the adjunction of several detection criterions can increase considerably the discriminatory capabilities of the fire detection systems.
• The dynamics of the various signals has to be taken into account in the fire alarm decision as an additional discriminatory factor. Performance development or qualification tests must be on one hand feasible under well controlled metrological conditions and on the other hand representative of a large range of realistic fire and non-fire situations.

**Conclusion and Future Scope**

New fire detection technologies bear the potential to improve the safety of aircraft by making a fire warning more reliable and by reducing the false alarm rate. Fire alarms and warning lights may occur when actually no engine fire exists. Such false alarms can be most easily located by disconnecting the engine sensing loop connections from the control unit. If the false alarm ceases when the engine sensing loop is disconnected, the fault is in the disconnected sensing loop, which should be examined for
areas that have been bent into contact with hot parts of the engine. However, the way to aircraft integration coincides with the fulfilment of stringent environmental and many other aircraft specific requirements. The technology that is used for fire detection instruments strongly influences the aircraft fire protection system and its integration.

Recently under investigation are advanced fire detection technologies with the aim to identify the proper fire signatures (gas, smoke, heat etc.) as they may develop in a crucial, inaccessible area of the aircraft and develop the algorithms which allow linking these fire parameters to non-fire events that may be present in the aircraft. In order to reduce the rates of alarm error, some soft computing models may be used such as artificial neural network, Fuzzy systems or fuzzy neural network for processing fire signal.

References


10. "International Conference on Automatic Fire Detection", AUBE '95, 10th, April 4-6, 1995.


Fig. 1 Thermocouple

Fig. 2 Bimetallic Switch

Fig. 3 Thermocouple Fire Warning Circuit

Fig. 4 Thermal Switch Fire Circuit

Fig. 5 Aircraft Fire Detection System Control Module
(FDs - Fire Detectors)

Fig. 6 Fire Detector Work Flow
Fig. 7 Fire and False Alarm Classification Logic

Fig. 8 Ratio Fire/False Alarm