ISRAEL AEROSPACE INDUSTRIES LTD

## Sixth Triennial International Fire & Cabin Safety Research Conference (Oct 25 - 28, 2010)

**Session: Cargo Fire**

# *IAI Bedek's Freighter Conversions Smoke Detection Systems*


***Presented by:***

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***Bedek Aviation Group, Aircraft & Programs Divisions***
***Israel Aerospace Industries***

# IAI Bedek Aviation Group, Aircraft & Programs Divisions

- Comprehensive maintenance services for narrow and wide body aircraft, engines and components.
- Modifications & upgrades for narrow and wide body aircraft.
- B767-200ER Multi-Mission Tanker-Transport.
- IAI Bedek holds Supplemental Type Certificates (STCs) for freighter conversions:
  - B737-300 PAX to special freighter (SF)
  - B737-400 PAX to SF
  - B747-100/200 PAX/Combi to SF
  - B747-400 PAX/Combi to SF
  - B767-200 PAX to SF
  - B767-200 Package Carrier (PC) to SF
  - B767-300 PAX to SF
- More than 150 IAI Bedek converted aircraft are operated all around the world with over than 2.0 million flight hours.
- No ADs issues regarding Bedek conversions.


# "Cargo Holds" Smoke Detection System: Design Philosophy

- New state-of-the-art cargo smoke detection systems (SDSs) developed in collaboration with SIEMENS SAS (France) - SIEMENS CoC for Airborne Systems.
- Latest technology smoke detectors:
  - Latest single / dual optical technology (high sensitivity to real fire).
  - High rejection of nuisance false alert signals.
- 2-LRU (Line Replaceable Units) architecture systems with cockpit control panel and smoke detectors.
- No electronic boxes in the E/E bay.
- FAR compliance & aviation standards:
  - Meeting the latest amendment of 25.858 known as the "one-minute" rule.
  - Developed following the guidelines of aviation industry standards including RTCA DO-160D/E, DO-178B, DO-254, SAE ARP 4754 and ARP 4761.
- High reliability design levels meeting 25.1309 definition.

# "Cargo Holds" Smoke Detection System: Design Philosophy

- Total loss of smoke detection in combination with a fire (< 1.7 E-07) is less than 1.00 E-09 per flight-hour.
- Flight continuation to target in the event of a system fault due to very low probability of system fault (< 1.00 E-05).
- The smoke detection systems contain Built-In Test Equipment (BITE) capabilities.
- Integrated to retain aircraft systems for both flight & maintenance operations similar to other fire protection systems (engines, APU, etc.):
  - Allows smoke alarm signal processing and identification of smoke detector(s) & zone(s) in alert.
  - Allows identification of faulty smoke detector(s) during power-up and flight.
  - Allows manual test of the smoke detection system and identification of smoke detector(s) "locked" in alarm.
  - Automatic detection logic reconfiguration to "Single loop" vs. smoke detector(s) fault status or in case of corresponding smoke detector(s) delay to respond to smoke alarm condition.

# "Cargo Holds" Smoke Detection System: Design Philosophy

- Replace lower cargo "passenger" smoke detectors with sensitivity of 88% by "freighter" high sensitivity 97% smoke detectors same as main cargo for maintenance commonality.
- Integrated cockpit control panel including all electronics and comply with vibration and EMI (Electro-Magnetic Interference) requirements.
- Balancing ECS air distribution system to reduce airflow streamline patterns and humidity at the vicinity of the "open-air" ambient smoke detectors thus eliminating the occurrences of false alarms.
- Provide procedures to eliminate the occurrences of false alarms due to humidity during taxi-out, takeoff, climb, descent, approach and taxi-in in summer and in tropical areas.
- Designed and tested to operate in both normal and faulty conditions (dispatch in case of smoke detector(s) or power failures).

# “Cargo Holds” Applications → Challenges


**Cargo applications**

**Various type of “freights”**

**Various Fire sources**

**Various type of “freights”**

**+ Cargo environment**

**Various False alarm sources**

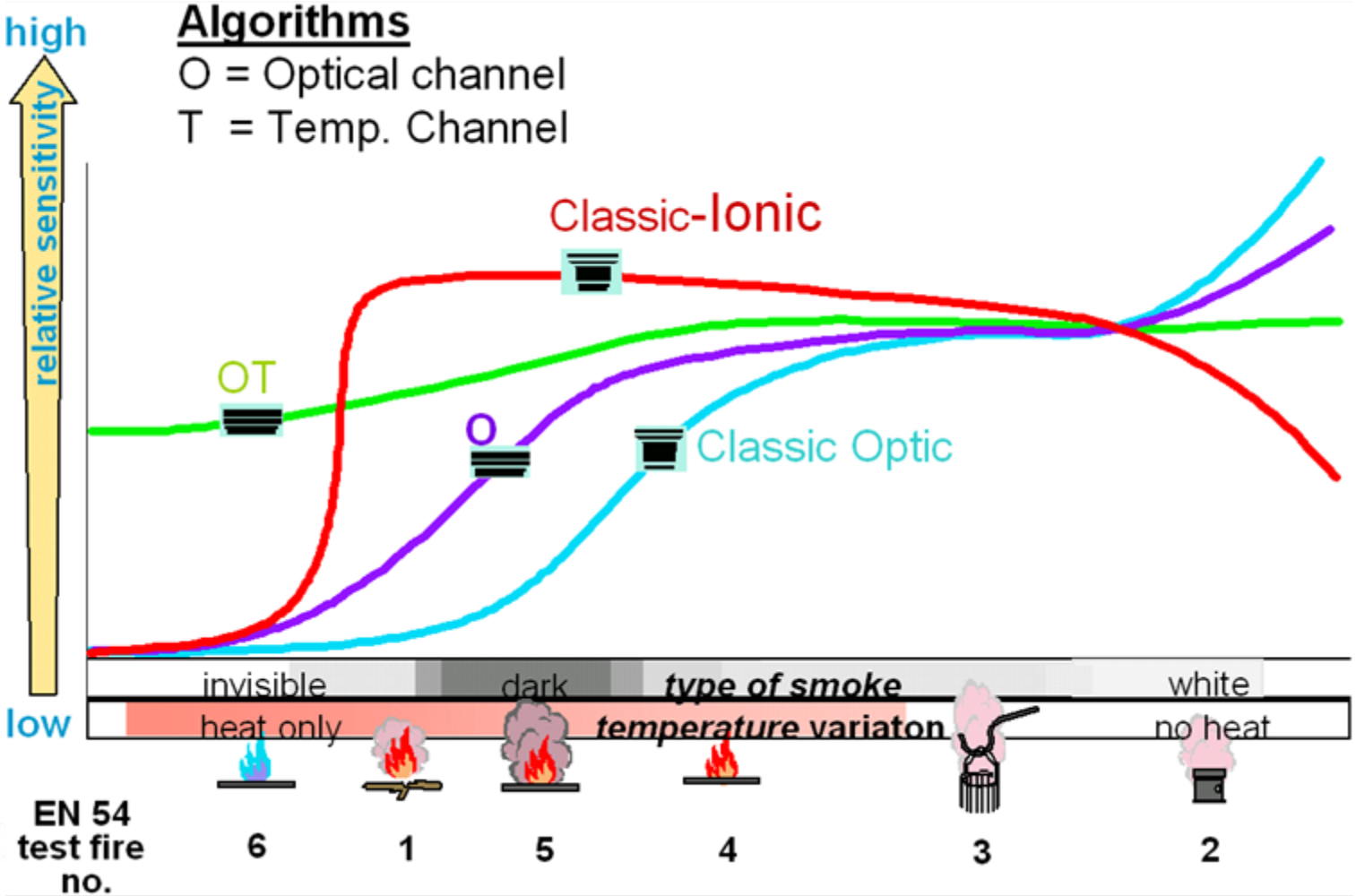
**Enhanced Fire detection spectrum**

**AND**

**High level of False alarm rejection**

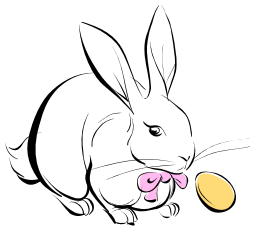
**“Cargo holds” applications require Smart Smoke Detection System**

# “Cargo holds” Applications → Fire Detection Spectrum




**With reference to EN54-7,**
**detectors shall have a balance sensitivity to all type of fire**

# Cargo Applications → False Alarm Rejection



- ***Cargo environment:***
- Large volume
- Ventilation (or not)
- Temperature control (or not)
- Altitude variation…

+

-***Type of Freight :***
- Perishables,
- Live stocks,
- Bulk freight,
- Others…


=

***Typical False Alarm (FA) sources such as:***
- Condensation, Moisture / Humidity,
- Haze, Fog, Dust, Insecticides…

**Cargo smoke detection system shall have the highest possible FA rejection rate against typical FA sources**

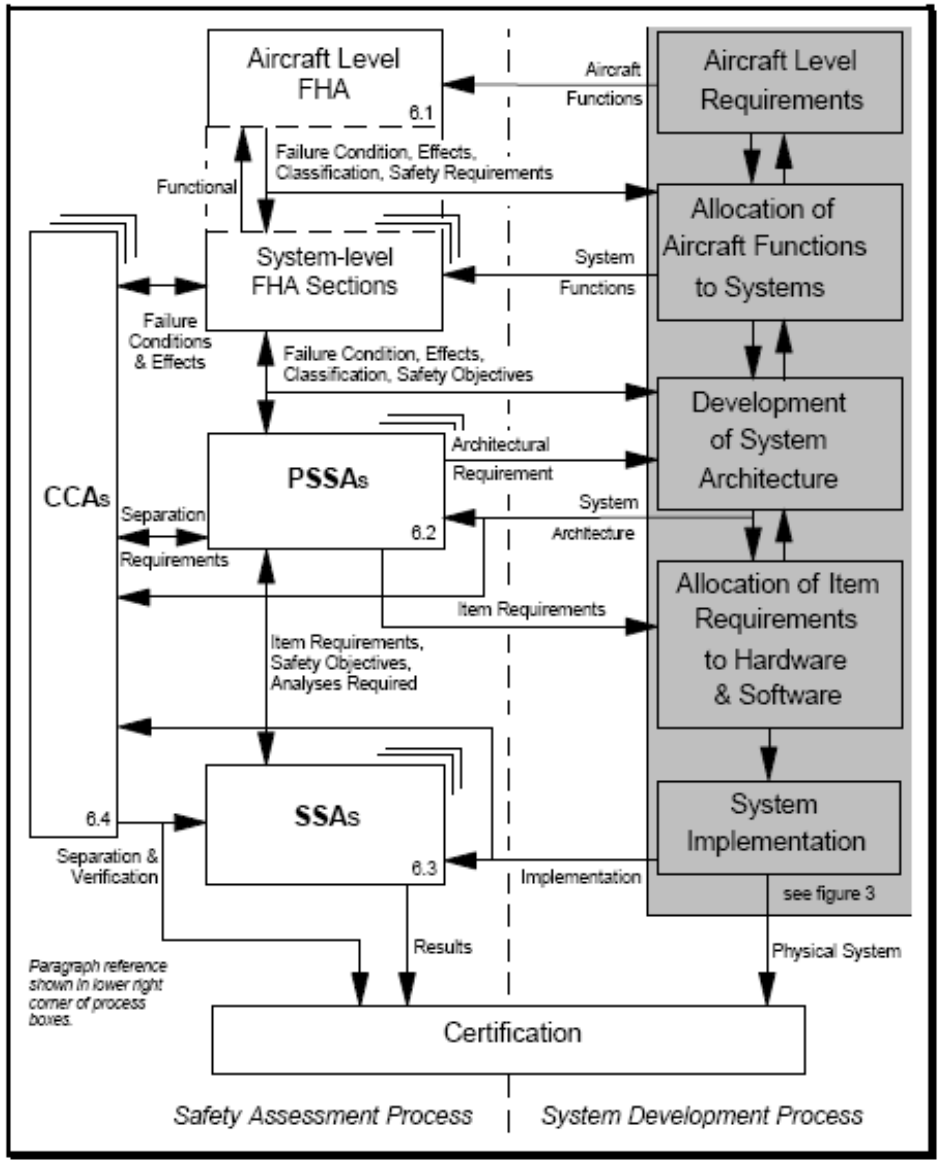
# Smoke Detection System Safety Requirements - 25.1309

FHA has been performed at A/C level and cascaded at system level, system failure conditions has been identified, classified as per severity, and associated probability of occurrence assigned as below:

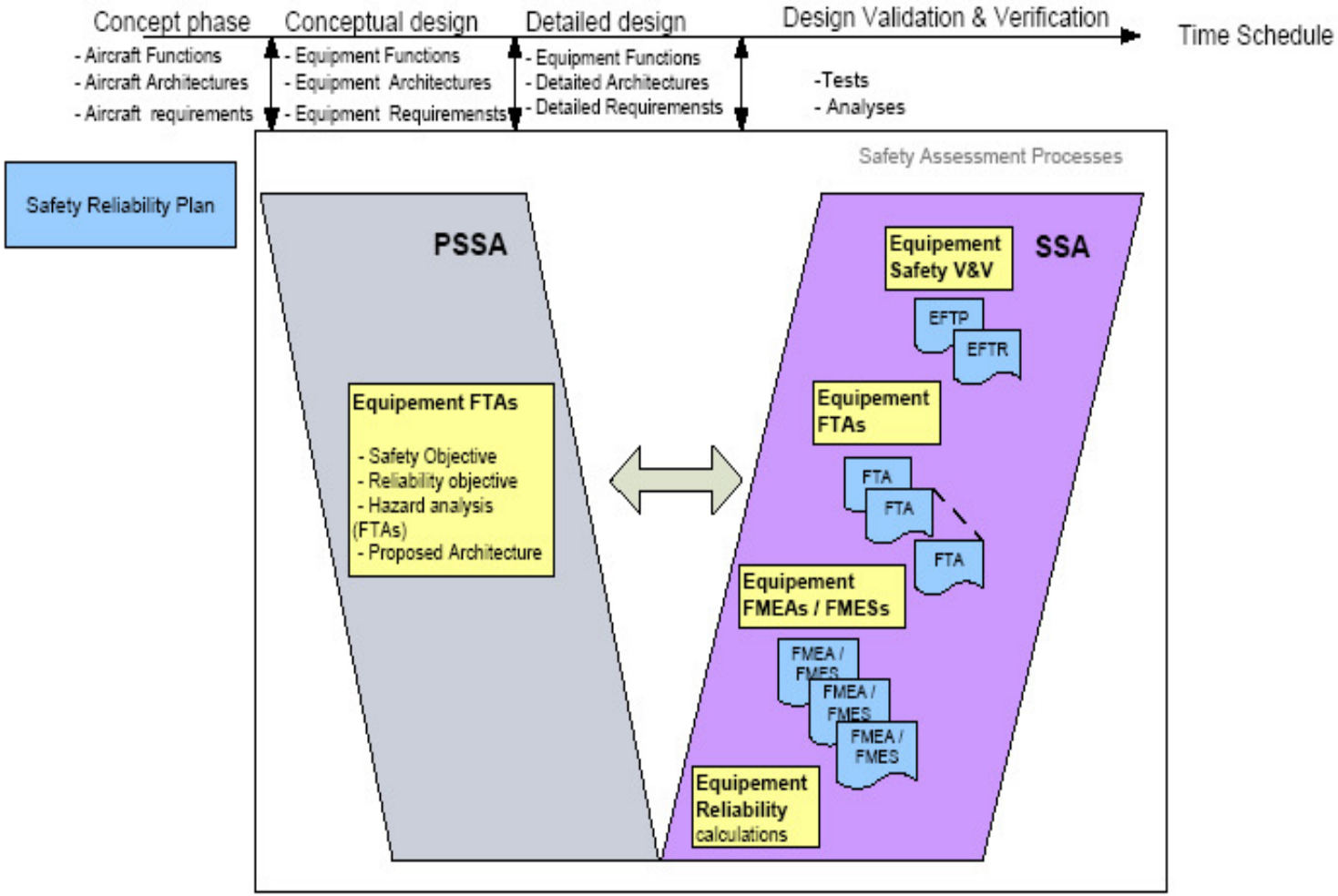
| Fault Conditions | Classification / Severity | Requirements (per FH) |
|---|---|---|
| Total loss of smoke detection in combination with a fire | Catastrophic | < 1.00 E-09 |
| Un-indicated loss of smoke detection capability without fire | Major | < 1.00 E-05 |
| Total loss of smoke detection in a cargo compartment zone without fire | Minor | < 1.00 E-03 |
| Spurious warning of smoke in a cargo compartment | Major | < 1.00 E-05 |

# System Safety Requirements vs. Development Processes

- System developed following SAE ARP 4754 (Certification Considerations for Highly-Integrated or Complex Aircraft Systems).
- Preliminary System Safety Assessment (PSSA) performed before development to:
  - Validate that architecture can meet safety objectives and identify necessary redundancies and define DAL.
- Safety System Assessment (SSA) performed after development process implementation including:
  - Reliability Prediction.
  - Failure Mode & Effects Analysis (FMEA).
  - Testability Analyses (failure coverage / hidden failure).
  - Common Mode Analyses (CMA).
  - Fault Tree Analysis (FTA).



# System Safety Requirements vs. Development Processes




- **Development Design Assurance Level B (DO178B / DO254).**
- **Environmental Qualification DO-160D/E.**

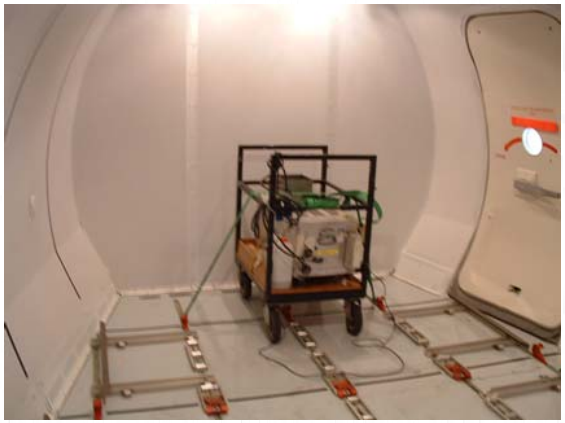
# “Cargo Holds” Fire Extinguishing System

- Early smoke detection to enable early operation of the fire fighting emergency procedures.
- Fire fighting emergency procedures based on:
  - Shut down air ventilation to the cargo compartments.
  - Supply fresh air to the occupied areas (flight deck and supernumerary area).
  - Main cargo Class E: Cabin depressurization and unpressurized flight at 25,000 ft altitude for oxygen deprivation.
  - Lower cargo Class C: Halon-based fire extinguishing system fired.
- Smoke penetration tests were performed to comply with 25.858(a) by filling the main and lower cargo compartments with smoke per FAA AC25-9A guidelines.

# “Cargo Holds” Fire Extinguishing System

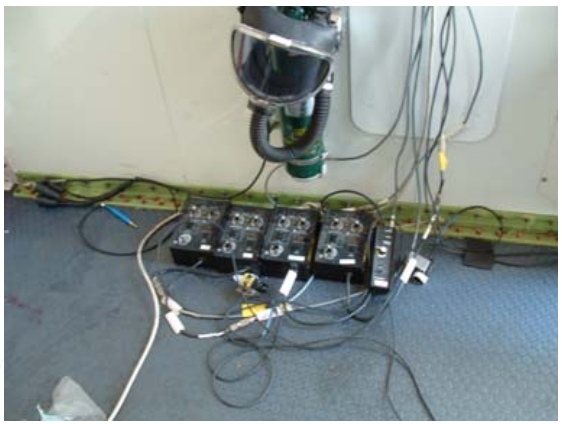
- No in-flight smoke penetrations to the occupied areas (flight deck and supernumerary area) were observed.
- No inadvertent smoke warnings were observed during smoke detection and penetration tests, in compliance with 25.855(i).

# Flight Test Equipment for Smoke Detection & Penetration Tests

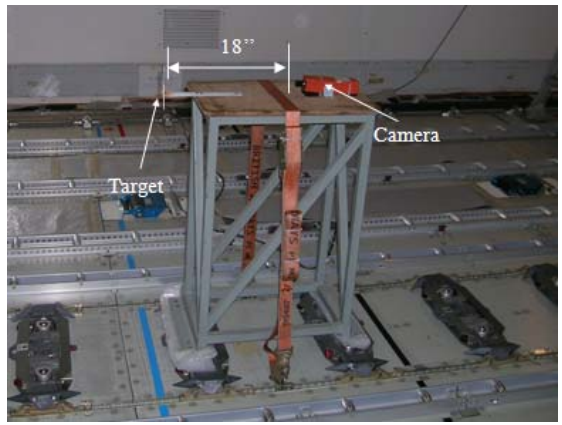


Kidde Aerospace modified smoke generator for smoldering "suitcase" smoke detection test


Set up for smoke penetration test



Remote controls of ROSCO smoke generators in supernumerary area




Camera and target for smoke penetration test

# B737-400 BDSF
# Smoke Detection System

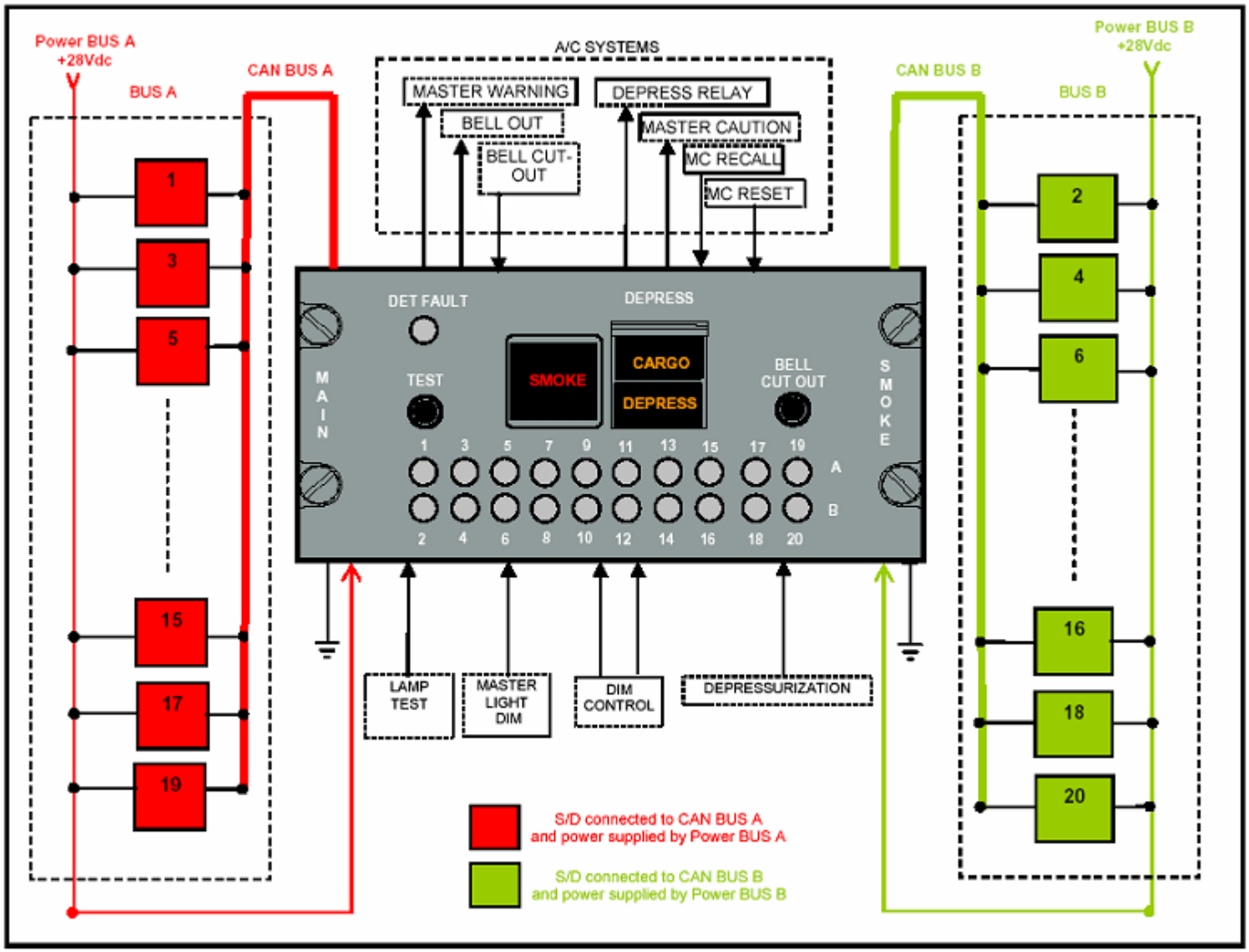
# B737-400BDSF Smoke Detection System

- Main cargo Class E.
- Reclassified incoming aircraft with lower cargo Class D to Class C by added STC kit (smoke detection & fire extinguishing).
- 2-LRU (Line Replaceable Units) architecture system with cockpit control panel and smoke detectors.
- No electronic boxes in the E/E bay.
- “Single loop” detection logic.
- Double segregated CAN (Controlled Area Network) bus systems for communication between the control panel and smoke detectors.
- Selected multi-criteria (MCR) “open-air” ambient type smoke detectors:
  - Dual optical chamber, temperature sensors, humidity sensor and a powerful detection algorithm.
  - Certified FAA / EASA TSO C1d.
  - Latest technology detector preventing nuisance false alert signals.

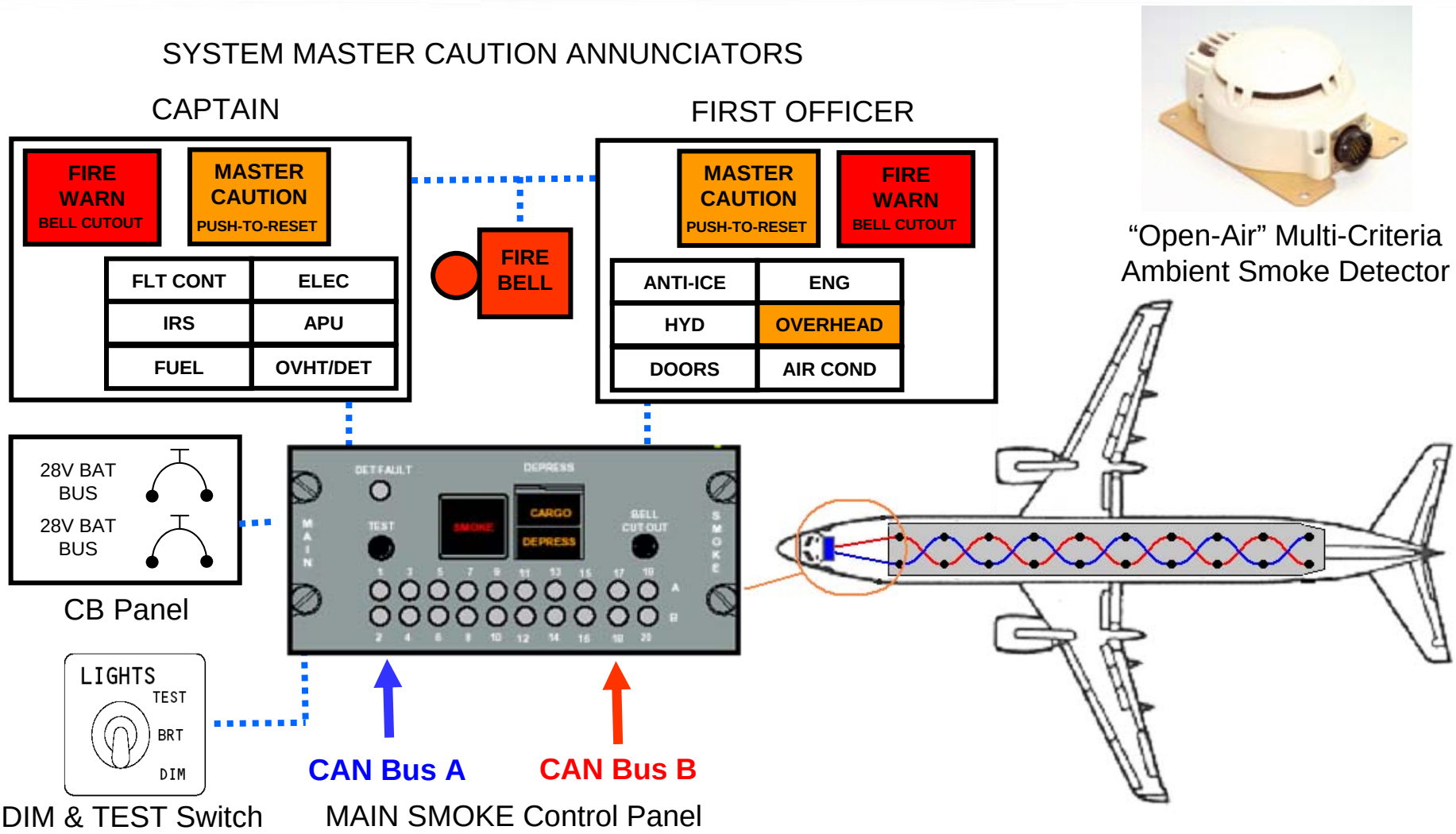
# B737-400BDSF Smoke Detection System

- FPGA (Field Programmable Gate Array) architecture.
- Flight testing showed dispatch capabilities in case of single failure (smoke detector or smoke detection bus power).

# Main Cargo Smoke Detection System Architecture



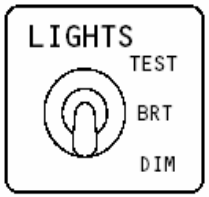
# Main Cargo Smoke Detection System Overview



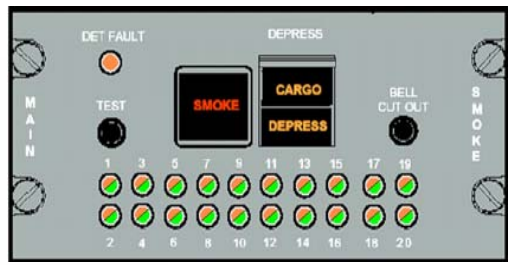



"Open-Air" Multi-Criteria Ambient Smoke Detector

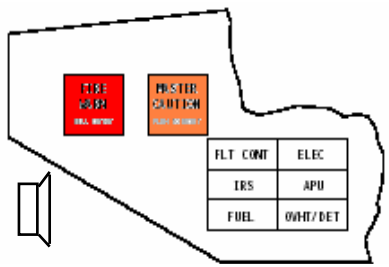
# Main Cargo Smoke Detection System Interface



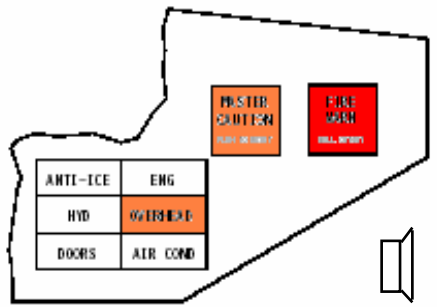

MASTER DIM & TEST SWITCH (ON P2)




MAIN SMOKE CONTROL PANEL (ON P5)



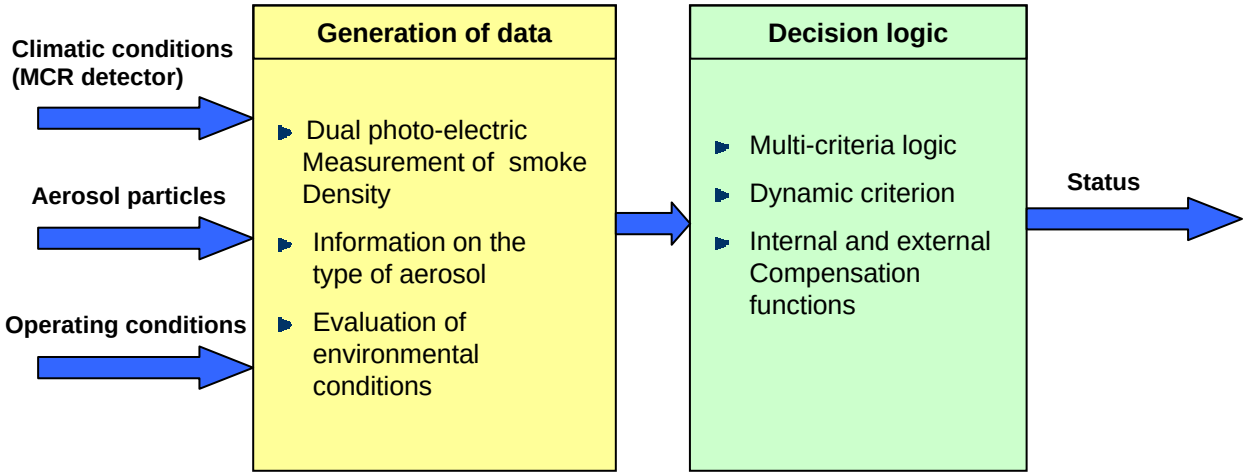

LEFT MASTER CAUTION AND FIRE WARN LIGHTS + BELL (ON P7)




RIGHT MASTER CAUTION AND FIRE WARN LIGHTS + BELL (ON P7)

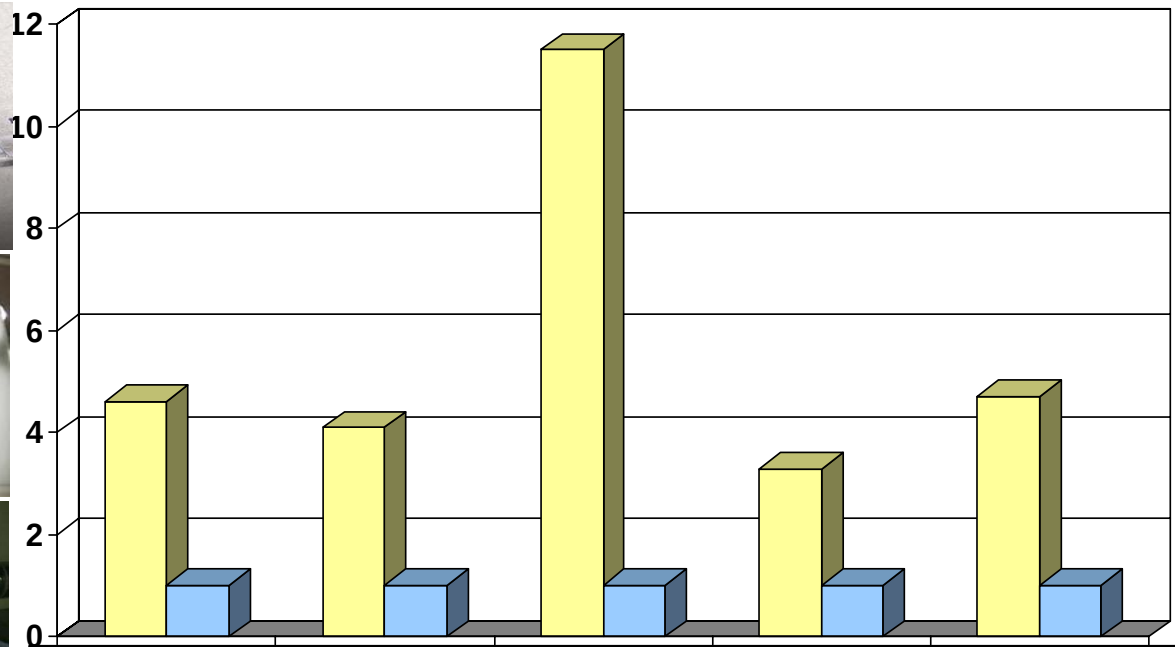
# Multi-Criteria smoke detector: Principle

Photo courtesy of Siemens




- **Largest fire detection spectrum (EN54-7):**
  - 2 optical channel for smoldering fire.
  - 2 thermal sensors for open fire (no smoke).
- **Highest level of FA rejection** thanks to:
  - Humidity sensor, Optical channels and algorithm balancing fire detection vs. FA scenarios (Dust, Haze, Fog, Insecticides, etc…).

# Multi-Criteria Smoke Detector: Performance against FA



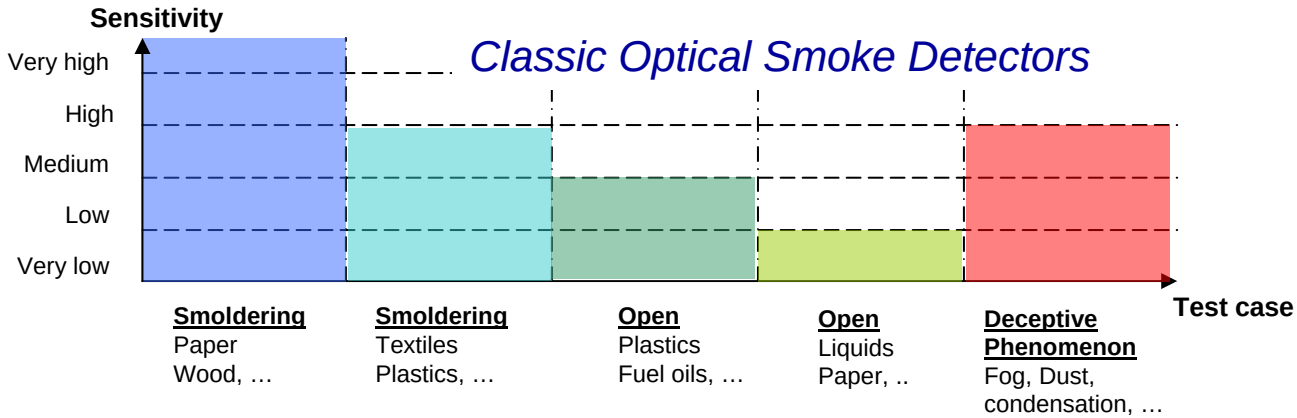

| | | Haze / Fog | Dust | Nucleic fog | Condensation | Insecticide |
|---|---|---|---|---|---|---|
| | MCR detector | 4.6 | 4.1 | 11.6 | 3.3 | 4.7 |
| Ref. | « Classic » optical detector | 1 | 1 | 1 | 1 | 1 |

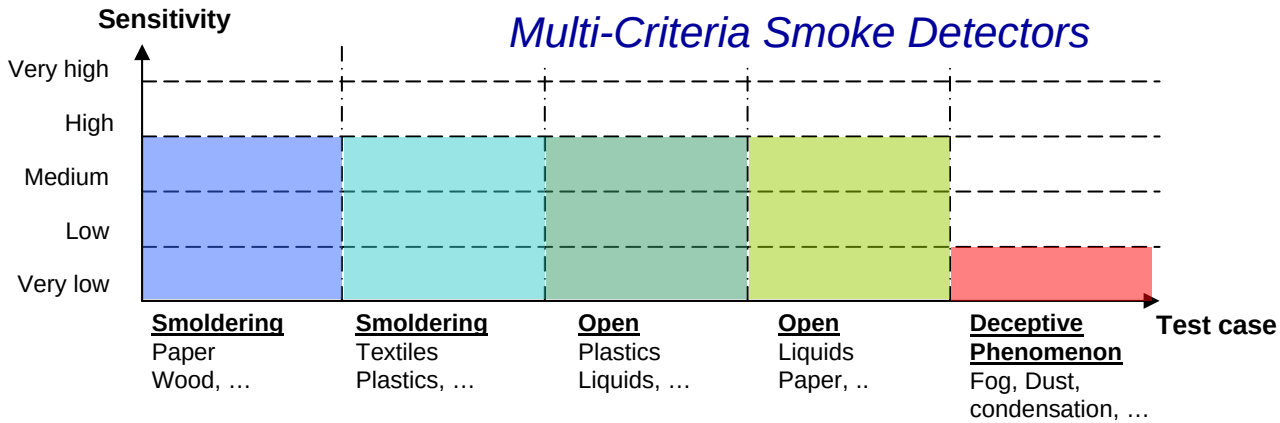
**MCR performance in “Rejection of False Alarm”**

**Is at least > 3 times better when compared to “classic” detector**

# Multi-Criteria Smoke Detector: Sensitivity to Real fire

Photos courtesy of Siemens




**Tests show that MCR is having a balance response to all type of fire, allowing a unique fire detection spectrum**

# Environmental Conditions and Test Procedures

| Qualification of 737-400BDSF Smoke Detection Equipments per DO-160E | | |
|---|---|---|
| **Test description** | **DO160E Chapter** | **Requirements** |
| Temperature | 4 | A3 (except for Ground Survival High Temperature and Short-time Operating High Temperature Test Equipment operation is not assured above 75°C |
| Altitude | 4.6.1 | A3 |
| Rapid Decompression | 4.6.2 | A3 |
| Overpressure | 4.6.3 | 15000 ft |
| Temperature Variation | 5 | C |
| Humidity | 6 | A |
| Operational Shock & Crash Safety | 7 | A Operational shock test only (3x6g in each perpendicular direction) |
| Vibration | 8 | S, curve B |
| Explosion | 9 | X (Not Applicable) |
| Waterproofness | 10 | X (Not Applicable) |
| Fluid susceptibility | 11 | F Solvents & cleaning fluids (spray test only) |
| Sand and Dust | 12 | X (Not Applicable) |
| Fungus resistance | 13 | F |
| Salt spray | 14 | X (Not Applicable) |
| Icing | 24 | X (Not Applicable) |
| Electrical - Power Inputs | 16 | A |
| Electrical – Voltage spikes conducted | 17 | A |
| EMC – Magnetic Effects | 15 | Z |
| EMC – AF conducted susceptibility | 18 | R |
| EMC – Induced Signal susceptibility | 19 | ZC |
| EMC – RF susceptibility (conducted) | 20 | R |
| EMC – RF susceptibility | | R |
| EMC – Emission of RF Energy | 21 | M |
| EMC – Lightning induced transient | 22 | A4 for power supplies, A2 for CAN lines, C3 for discrete I/O |
| EMC – Lightning direct effects | 23 | X (Not Applicable) |
| EMC – Electrostatic discharge | 25 | A |
| Flammability | 26 | C |

# B747-400 BDSF
# Smoke Detection System

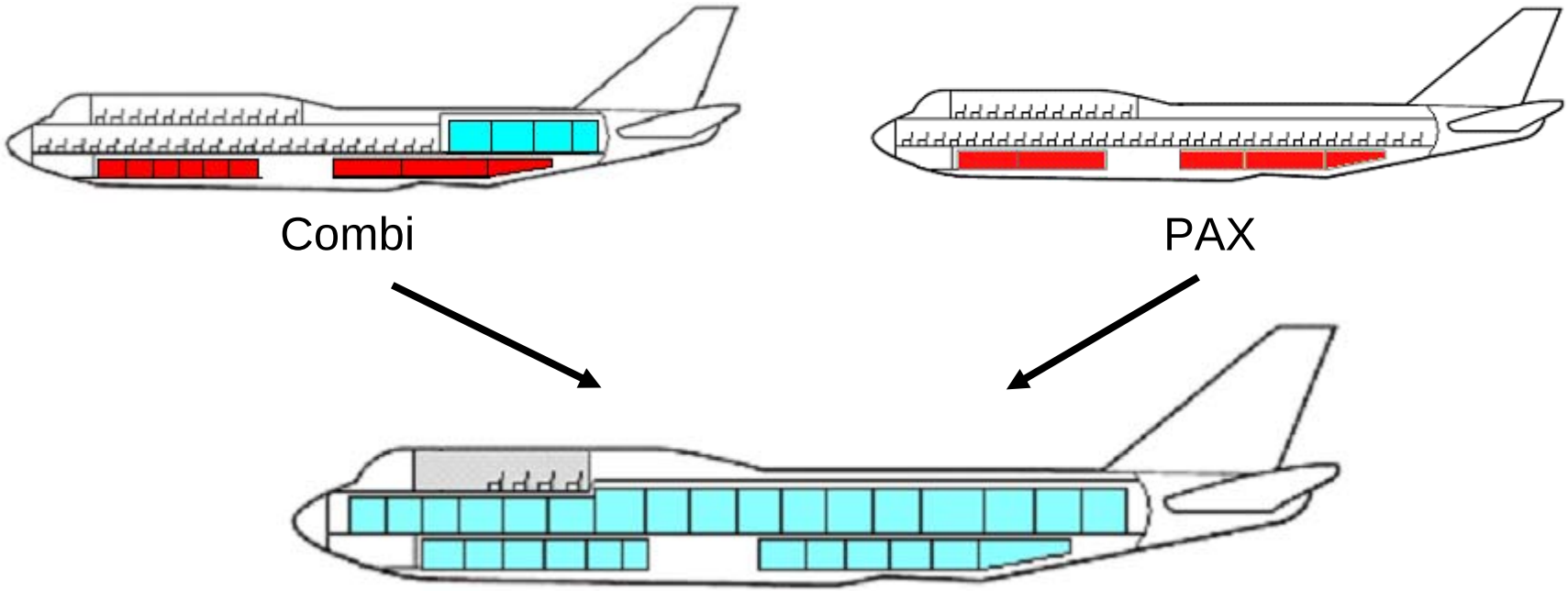
# B747-400BDSF Smoke Detection System

- Main cargo Class E.
- Lower fwd & aft cargo Class C remain unchanged.
- Added air conditioning in the lower fwd & aft cargo.
- 3-LRU (Line Replaceable Units) architecture system with cockpit control panel, smoke detectors and maintenance controller.
- Maintenance controller is located in the cockpit maintenance panel P61 easy reached by the pilots.
- “Dual loop” detection logic based on “freighter” high sensitivity (97%) “open-air” ambient type smoke detectors certified FAA / EASA TSO C1c.
- CAN (Controlled Area Network) bus communication between the maintenance controller and smoke detectors.
- Approximately one to two meters distance between Loop A and Loop B smoke detectors to eliminate the occurrences of false alarms under humidity condition.

# B747-400BDSF Smoke Detection System

- Two LCD screens, one per loop, provide the means to isolate faults of each smoke detector.
- Automatic and real time reconfiguration to “Single loop” detection logic per zone in case of smoke detector’s fault or corresponding smoke detector(s) delay to respond to smoke alarm condition.
- Same smoke detectors in main and lower cargo compartments for maintenance commonality.
- Analysis showed that the additional of air conditioning system in the lower cargo Class C, would not affect the Halon concentration required by the regulations during fire fighting emergency conditions.
- Flight testing showed dispatch capabilities in case of single failure (smoke detector, entire smoke detection loop or smoke detection bus power).

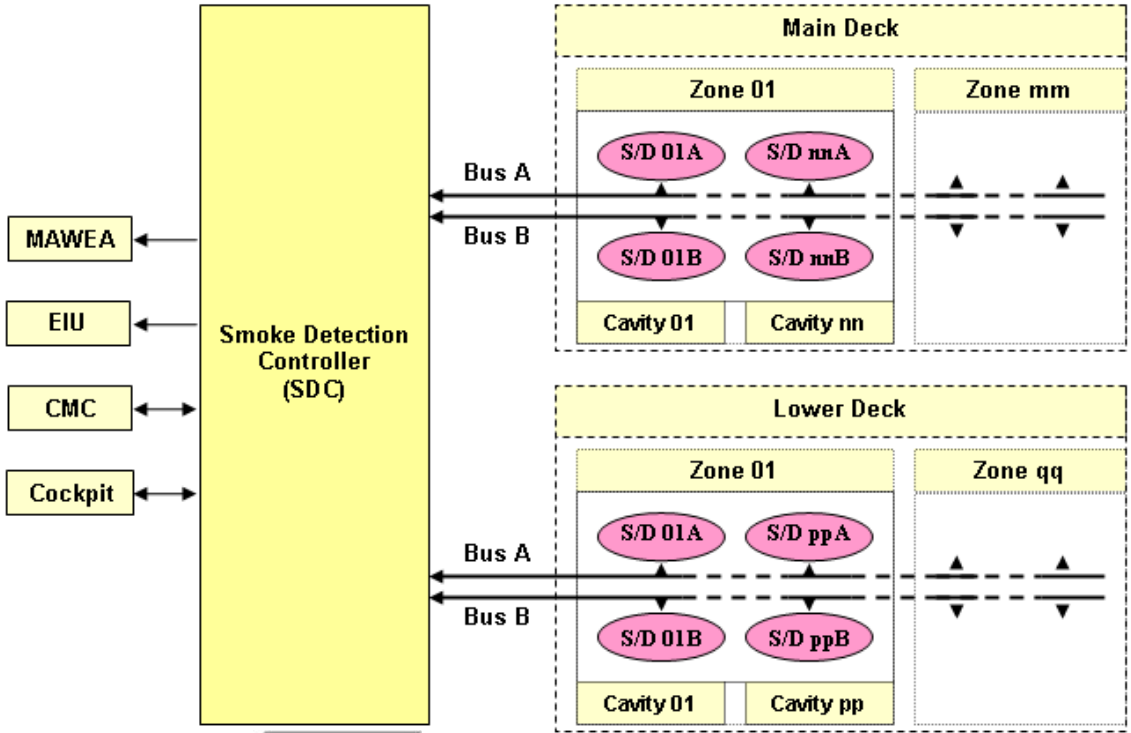
# Modification Areas

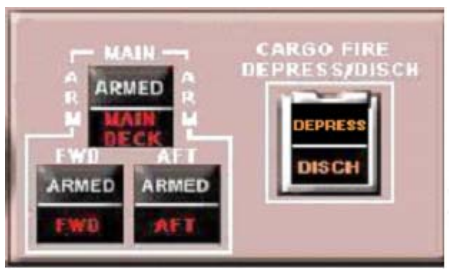


# Cargo Smoke Detection System Overview

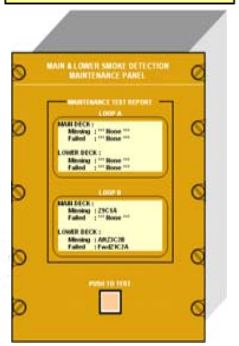
| | PAX/Combi | | Special Freighter | |
|---|---|---|---|---|
| | Main Deck | Lower Cargo | Main Deck | Lower Cargo |
| Cargo Compartment Classification | N/A (PAX) / C (Combi) | C | E | C (unchanged) |
| Smoke Detection Time Requirement | "5-minute" rule | "5-minute" rule | "1-minute" rule | "1-minute" rule |
| Smoke Detection System Type | "draw-through" air sampling | "draw-through" air sampling | "open air" ambient detectors | "open air" ambient detectors |
| Fire Extinguishing System | Halon and/or Portable Bottles | Halon | Depressurization | Halon (unchanged) |

# Smoke Detection System Architecture



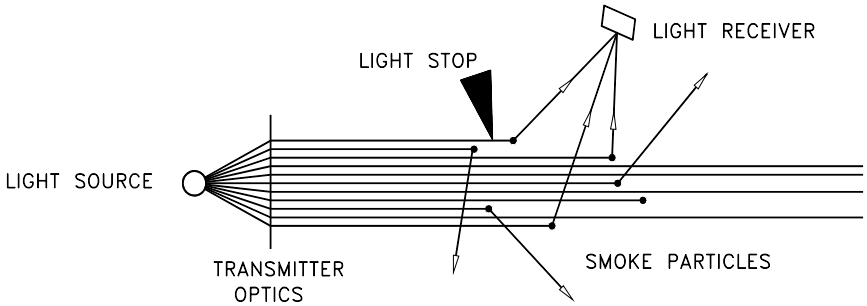

Control Panel



Maintenance Controller

"Open-Air" Ambient Smoke Detector

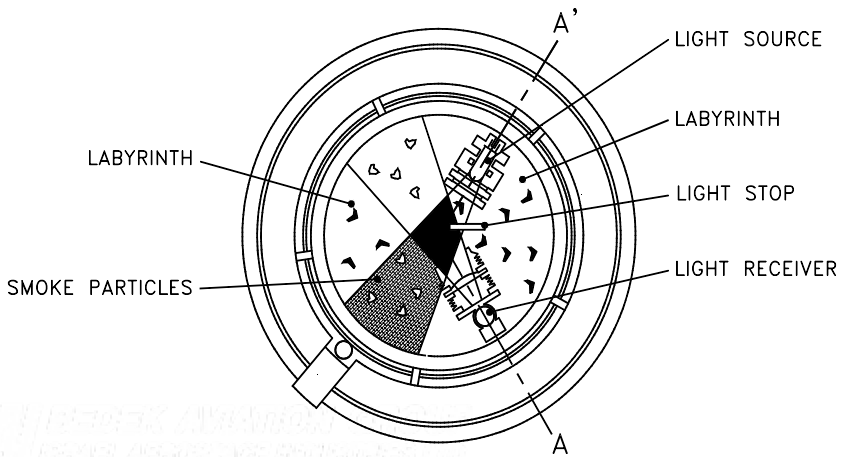
# Siemens “Open-Air” Ambient Optical Smoke Detector: Principle




SCATTERED LIGHT PRINCIPLE

- Infrared light wave (880 nm) emitted in brief pulses (400 µs)

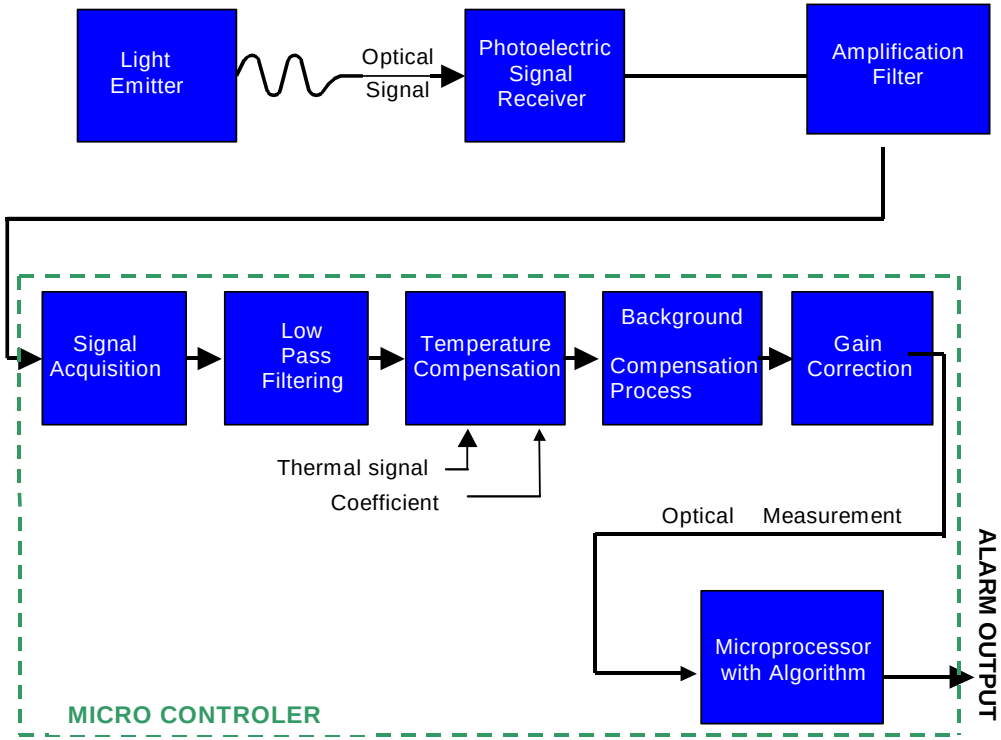
- Positioning of receiving cell allowing very high quantum efficiency




MEASUREMENT CHAMBER

- Unique Labyrinth design ensuring no deposition of water particles/ condensation to improve FA rejection

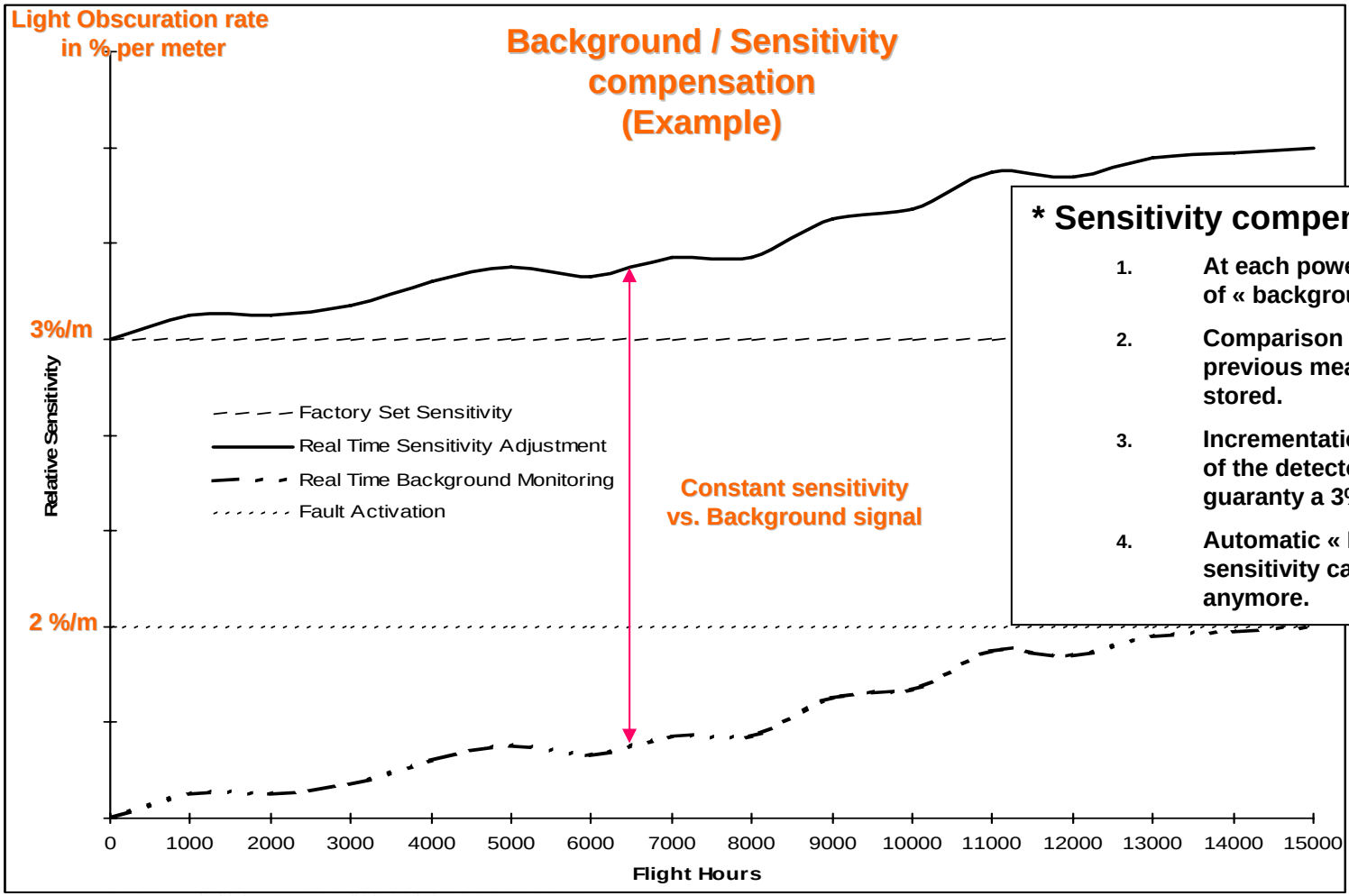
# Siemens "Open-Air" Ambient Optical Smoke Detector: Principle




- **Microprocessor controlled electronics with algorythm for FA rejection**
- **Optimized sensitivity calibrated at 3%/m (*) to ensure an optimal fire detection spectrum**

  **(*) Percentage of light obscuration over a distance of 1 meter**
- **« Background » measurement to allow a constant sensitivity and real time « fault » activation in case of contamination**
- **A Built In Test Facility allowing a complete functional check and a real time failure indication on ground or in flight**

# Siemens “Open-Air” Ambient Optical Smoke Detector: Principle




*** Sensitivity compensation principle:**

1. At each power-up, measurement of « background signal value».
2. Comparison of the value with previous measurement value stored.
3. Incrementation or decrementation of the detector sensitivity to guaranty a 3%/m relative sensitivity.
4. Automatic « Fault » activation if sensitivity can not be garrantied anymore.

# Environmental Conditions and Test Procedures

| Qualification of 747-400BDSF Smoke Detection Equipments per DO-160D | | | |
|---|---|---|---|
| **Test description** | **DO160D Chapter** | **Requirements** | |
| | | **SDC** | **S/D** |
| Temperature | 4 | A2 | A3 |
| Atmospheric pressure – Altitude | 4 | Maximum decompression altitude : 50000 feet | |
| Temperature Variation | 5 | C | B |
| Humidity | 6 | A | C |
| Operational Shock & Crash Safety | 7 | B | B |
| Vibration | 8 | S, curve B | R, curve C1 |
| Explosion | 9 | X (Not Applicable) | |
| Waterproofness | 10 | X (Not Applicable) | |
| Fluid susceptibility | 11 | X (Not Applicable) | F, immersion test Not Applicable |
| Sand and Dust | 12 | X (Not Applicable) | |
| Fungus resistance | 13 | F | |
| Salt spray | 14 | X (Not Applicable) | S |
| Icing | 25 | X (Not Applicable) | |
| Electrical - Power Inputs | 16 | A (CF) | |
| Electrical – Voltage spikes conducted | 17 | A | |
| EMC – Magnetic Effects | 15 | C | A |
| EMC – AF conducted susceptibility | 18 | A | |
| EMC – Induced Signal susceptibility | 19 | Z | |
| EMC – RF susceptibility (conducted) | 20 | R | |
| EMC – RF susceptibility (radiated) | | R | CW & SW :<br>▪ 0.1-1GHz : 10V/m;<br>▪ 1-8GHz : 40V/m.<br>PW :<br>▪ 0.4-1GHz : 150V/m;<br>▪ 1-6GHz : 300V/m;<br>▪ 6-8GHz : 60V/m. |
| EMC – Emission of RF Energy | 21 | L | M |
| EMC – Lightning induced transient | 22 | A4E3 | A4 for power supply<br>A2 for others |
| EMC – Lightning direct effects | 23 | X (Not Applicable) | X (Not Applicable) |
| EMC – Electrostatic discharge | 25 | A | |

# B767-200/300 BDSF Smoke Detection System

# B767-300BDSF Smoke Detection System (SDS)

- Main cargo Class E.
- Lower fwd & aft cargo Class C remain unchanged.
- Existing lower fwd cargo air conditioning remains unchanged.
- Added lower fwd cargo air conditioning for incoming aircraft without air conditioning - option.
- 2-LRU (Line Replaceable Units) architecture system with control panel and smoke detectors.
- No electronic boxes in the E/E bay.
- “Freighter” high sensitivity (97%) “Draw-thru” smoke detectors certified FAA / EASA TSO C1c.
- “Dual loop” detection logic per zone.
- Permanent smoke detector status fault monitoring and indication.
- Same smoke detectors in the lower and main cargo compartments for maintenance commonality.

# B767-300BDSF Smoke Detection System (SDS)

- Automatic reconfiguration to “Single loop” per zone in case of detector(s) fault or corresponding smoke detector(s) delay to respond to smoke alarm condition.
- Adding in-line heaters upstream the smoke detectors to prevent false alarms in perishable mode of operation (main cargo temperature 4 Celsius degrees).
- Inhibit lower cargo smoke detection system in case of main cargo smoke mode operation to prevent inadvertent smoke alarms.
- Flight testing showed dispatch capabilities in case of single failure (smoke detector, entire smoke detection loop or bus power).

# B767-300BDSF Main Cargo Smoke Detection System


COMBINED MAIN DECK CARGO FIRE & FAULT ISOLATION CONTROL PANEL

EXISTING FLIGHT DECK WARNING & INDICATIONS

EICAS – TOP & BOTTOM DISPLAY UNITS

FIRE/OVHT TEST PANEL


LAMP TEST SWITCH

FIRE BELL AURAL WARNING LOUDSPEAKERS

WARNING

CAUTION

MASTER WARNING & CAUTION


DISCRETE WARNING DISPLAY MODULE

M/D Zone 1 Zone 2 Zone 3 Zone 4 Zone 5 Zone 6 Zone 7 Zone 8

FWD

A B A B A B A B A B A B A B A B

HEATER CONTROLLER

PERISHABLE

NORMAL /ANIMALS

MAIN DECK CARGO TEMP RANGE SELECTOR LOCATED ON P61 MAINTENANCE PANEL (FLIGHT DECK)

TO EICAS BOTTOM DISPLAY

Opens for pressure below 4 in-H2O

P

WING BOX

BLEED AIR FROM PNEUMATIC CROSSOVER DUCT

EXHAUST TO MIX BAY AREA

EJECTOR PUMP

LEGEND:

SENSING LINE

VACUUM LINE

MOTIVE FLOW

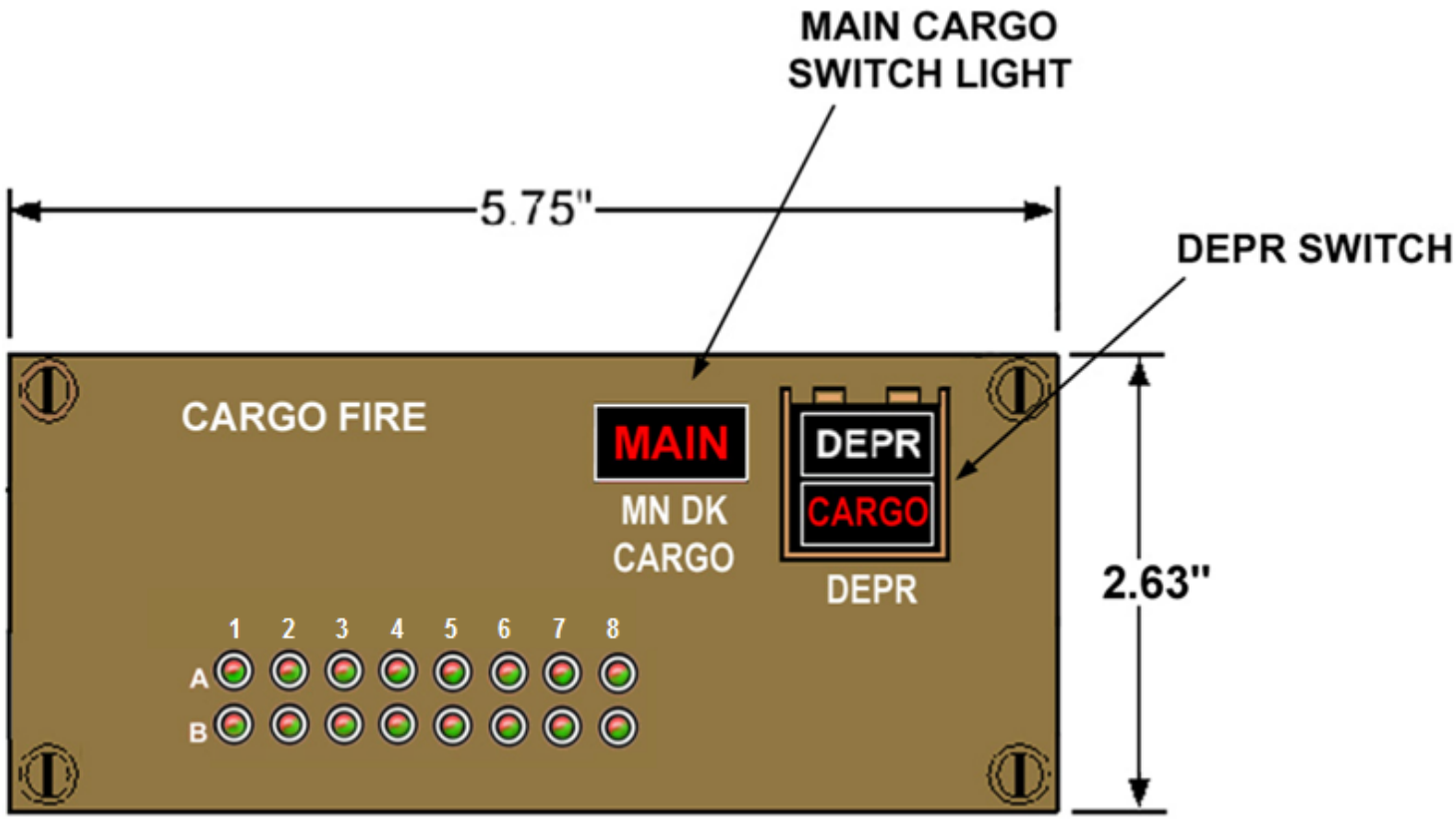
ELECTRICAL CONNECTION

SENSING PORT "SNIFFER"

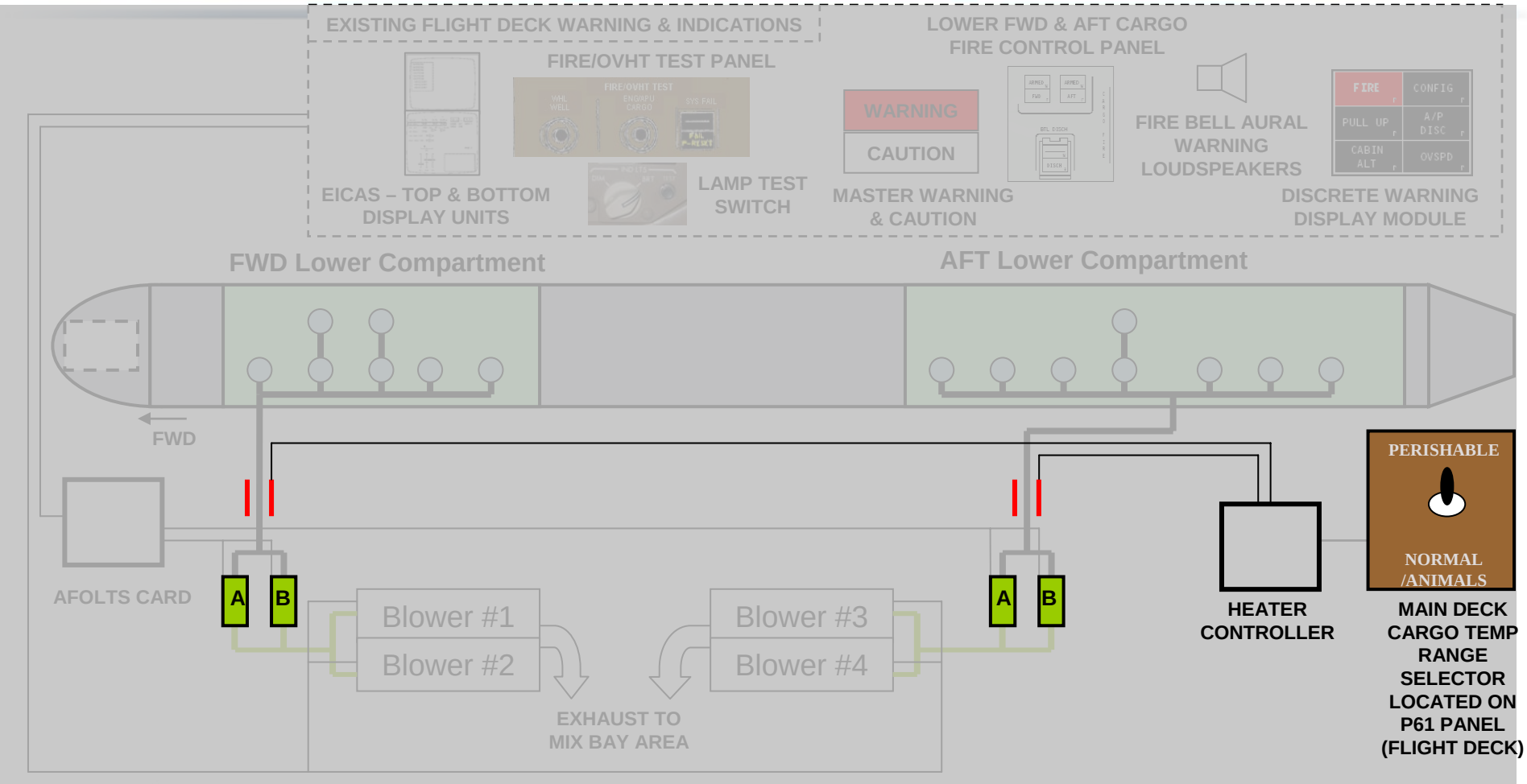
SMOKE DETECTOR

TUBE HEATER

# B767-300BDSF Main Cargo Smoke Detection System Control Panel



# B767-300BDSF Lower Cargo Smoke Detection System

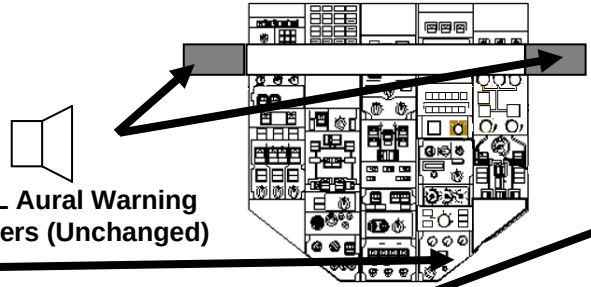



**LEGEND:**

- SENSING LINE
- VACUUM LINE
- ELECTRICAL CONNECTION
- SMOKE DETECTOR
- SENSING PORT "SNIFFER"
- TUBE HEATER

# Flight Deck Instruments Related to the Main Cargo SDS

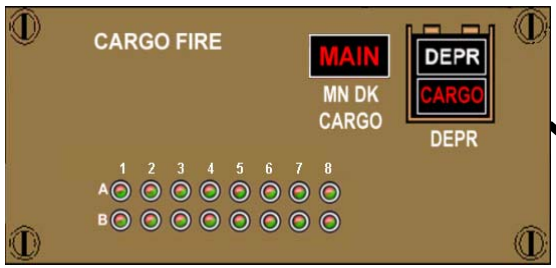

Indication Light
Test Switch (Unchanged)



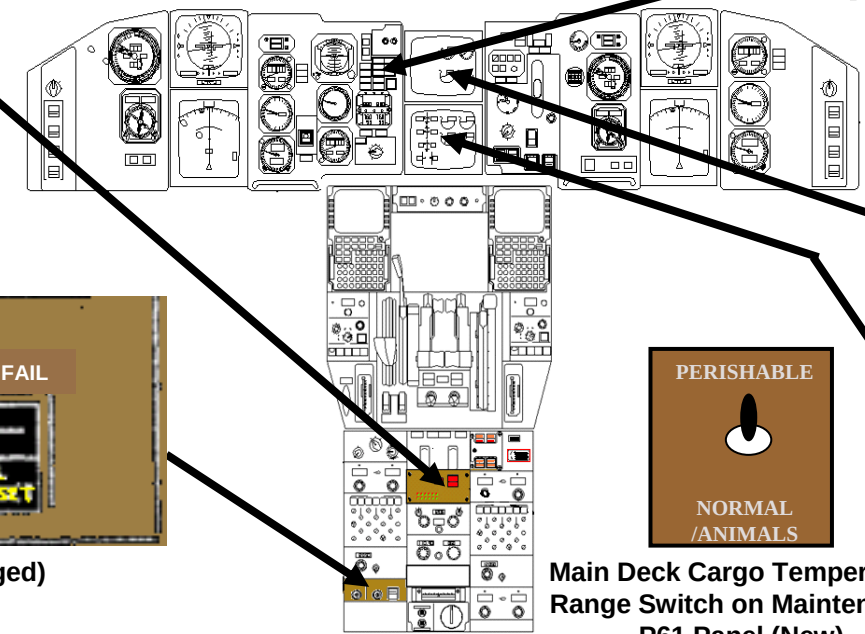
FIRE BELL Aural Warning
Loudspeakers (Unchanged)

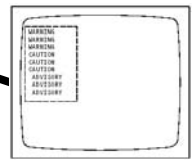

Master
Caution and Warning Lighted
Switch (Unchanged)


Discrete Warning Display
Module (Unchanged)




Main Deck CARGO FIRE Control Panel
(New)



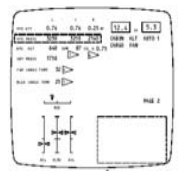


Top EICAS Display Unit
for Alert Messages
(Unchanged)


FIRE/OVHT TEST PANEL (Unchanged)

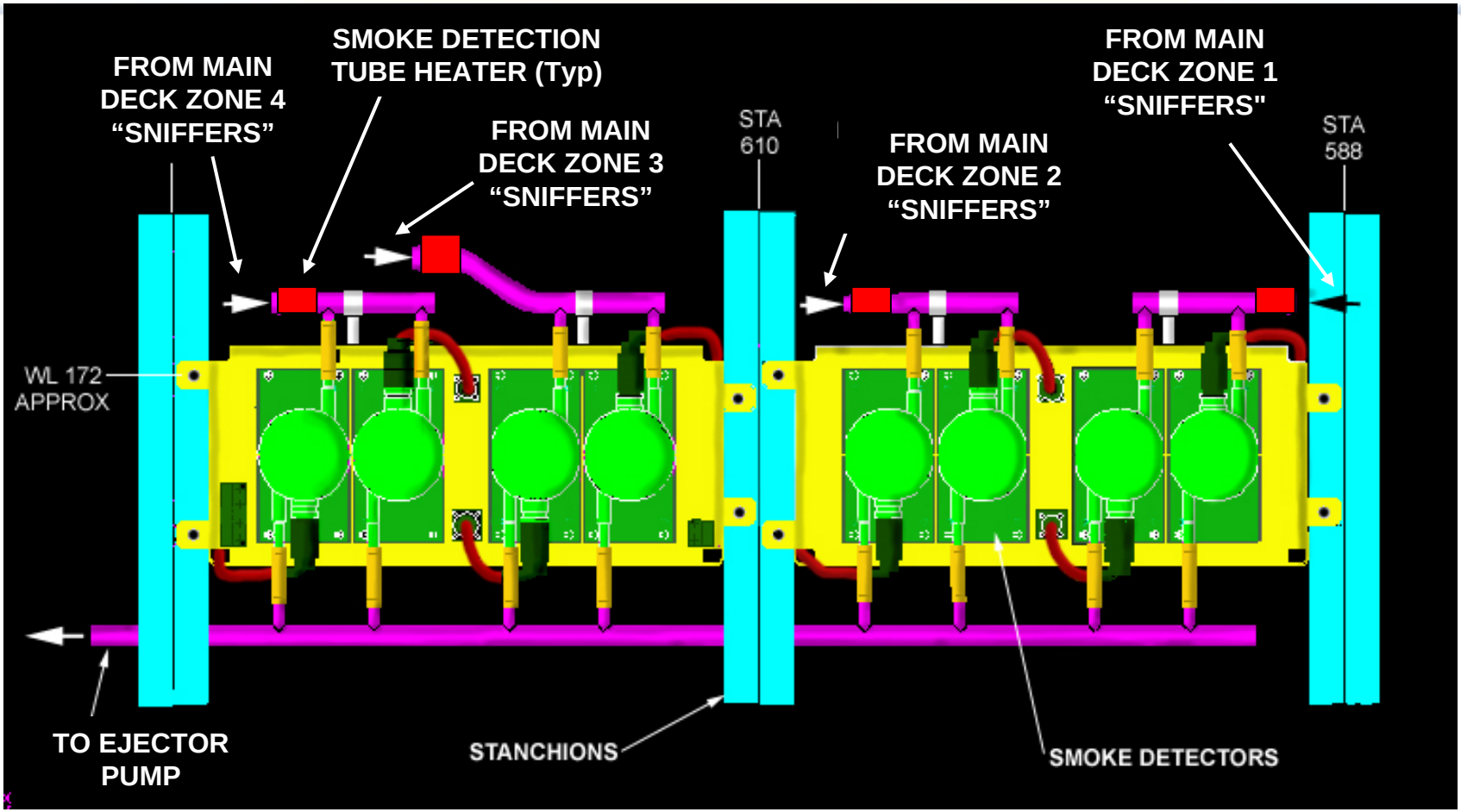



Main Deck Cargo Temperature
Range Switch on Maintenance
P61 Panel (New)



Bottom EICAS Display Unit
for Status / Maintenance
Messages (Unchanged)

# Main Cargo Smoke Detectors Installation




Smoke detectors installation in lower fwd cargo for main cargo zones 1 to 4, similar installation in the lower aft cargo for main cargo zones 5 to 8.

# Siemens "Ducted" Type Optical Smoke Detector: Principle

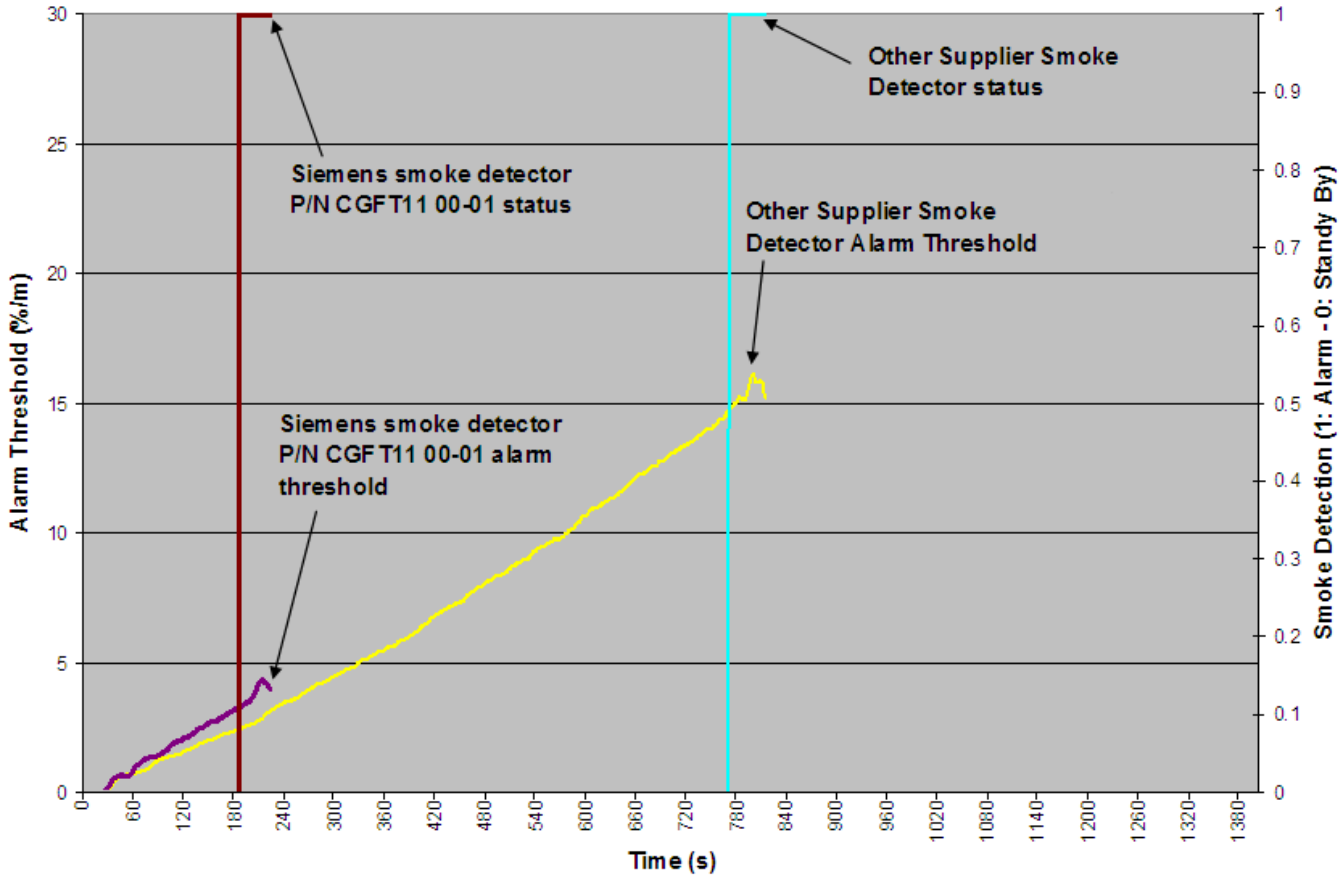
Photo courtesy of Siemens

- Microprocessor controlled electronics with algorythm for FA rejection
- Unique labyrinth design ensuring no deposition of water particles/ condensation to improve FA rejection
- Optimized sensitivity calibrated at 3%/m (*) to ensure an optimal fire detection spectrum

  (*) Percentage of light obscuration over a distance of 1 meter
- « Background » measurement to allow a constant sensitivity and real time « fault » activation in case of contamination
- A Built In Test Facility allowing a complete functional check and real time failure indication on ground or in flight

# Smoke Detector Sensitivity Comparison

**Test Bench Set-Up: Airflow 30 LPM, Velocity 0.2 m/s**
**Obscuration rate (%/m) measured with external device**




**Siemens "freighter" smoke detector detected smoke after 186 seconds for alarm threshold of 3.5 %/m. Other supplier "freighter" smoke detector detected smoke after 775 seconds for threshold of 15.5%/m**