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Test methods and apparatus for a video-based system designed for cargo fire verification

Abstract

A video-based fire and smoke detection system for cargo bays of airplanes has been developed by the Goodrich Corporation. It was necessary to create a suite of fire sensitivity and false alarm immunity tests applicable to these vision based fire detection systems. This paper will concentrate on testing aspects and test cell modifications.

Introduction

False alarms of smoke detectors in cargo compartments are an extremely rare event, but there is a growing risk with view to long-range operation of airplanes, especially on polar routes. Against the background of high costs caused by false alarms of smoke detectors in cargo bays of airplanes, a video-based smoke detection system (**C**argo **F**ire **V**erification **S**ystem - **CFVS**) has been developed. Currently, if a smoke alarm occurs, the crew must activate the extinguishing system and land at the nearest suitable airport. High costs are caused by flight diversions, landing costs and loss of the cargo load. The pilot has no capability to verify if the alarm is real or false. Possible reasons for false alarms of traditional smoke detectors are mist, dust, oil particles. Additional problems in cargo compartments are environmental conditions such as temperature variation and air pressure variation. The objectives of the Cargo Fire Verification System are to provide the aircrew with images of the conditions in the cargo bay, to detect fire earlier than conventional smoke detectors, and to greatly reduce false alarms.

Aircraft cargo compartments

Cargo compartments of passenger aircraft are located below the passenger cabin and are not easily accessible during flight. They are a difficult area to view with video cameras because the gap between the cargo and the cargo bay ceiling can be as small as 4.3 cm.

For reference, the size of an Airbus A340-500 aft compartment is 10.4 m long, 4.2 m wide, and 1.7 m high. The A340-500 contains 3 cargo compartments, referred to as the Forward (in front of the aircraft), Aft, and Bulk cargo bays (behind the wing boxes). Figure 1 shows how the cargo compartment can be nearly completely filled with cargo containers.

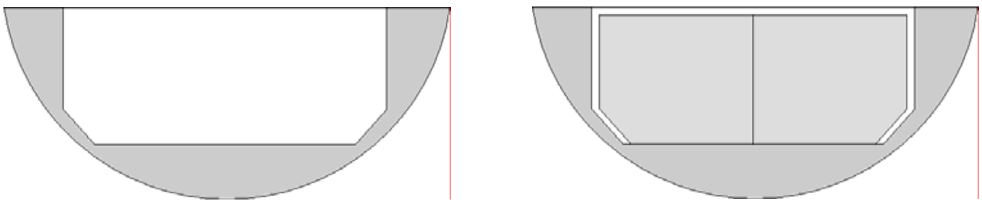


Fig. 1 Section views of a cargo compartment without (L) and with (R) containers

Video-based detection system

The functional objectives of the Cargo Fire Verification System are to provide the aircrew with images of the conditions in the cargo bay, to detect fire and smoke faster than conventional smoke detection systems, and to be immune to typical false alarm sources. Thus, the CFVS primary detection must be video based [1].

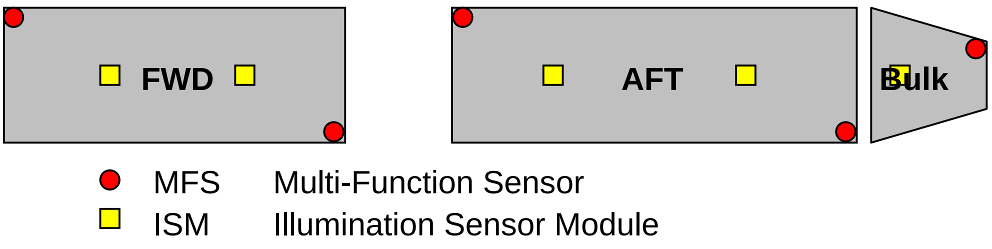


Fig. 2 Example CFVS aircraft installation, top view

The CFVS was developed by Goodrich Corporation. It consists of Multi-Function Sensors (MFS), Illumination Sensor Modules (ISM), and a Cargo Fire Verification Control Unit (CFVCU). The MFS includes a near-infrared filter and CCD video camera, integrated LEDs for illumination, a Digital Signal Processor for image analysis, and a lens window heater to prevent condensation in the field of view. Near-infrared functionality ensures operation without visible lighting in the cargo bay. The MFS provides real time video and image statistics to the CFVCU. The MFS's are mounted in the cargo compartment to maximize volumetric coverage of the compartment.
The ISM consists of near-infrared illumination LED's, a temperature sensor, and a humidity sensor. Sensor data is provided to the CFVCU. ISM's are mounted in the ceiling of the cargo compartment. The CFVCU provides system operation control, sensor data fusion, smoke alarm decision making, video storage for replay, and cockpit display interfaces. The CFVCU is typically installed in an avionics bay. Figure 2 shows a representative CFVS installation.

Depending on the light conditions, each camera provides four different views of the scene. The thermal view, i.e. all lights off is designed for hot spot detection, also flame reflections can be seen. The diagonal view with opposite camera light on is used to study the CFVS performance in dust. The pilot view with own camera light on shows the gap between a cargo container and the top of a cargo bay. Figure 3 is an image of four views with different illumination, but same geometric condition.

Testing of video-based systems

The existing testing guidelines and standards for qualification of current smoke detection systems were formulated mainly to address the case of traditional detection technologies, e.g., optical-based smoke detectors. In many cases, the qualification tests were derived from the EN-54 [2] fire sensitivity tests, which were originally developed for testing smoke detectors in buildings. In short, the EN-54 tests consists in different types of smoke sources at the center of the floor of a large test chamber.

During the tests, the smoke density at the location of the smoke detector and the alarm time of the detector are measured. The geometry and contents of the test chamber are not critical to the smoke detectors if the smoke density increases within the EN-54 guidelines.

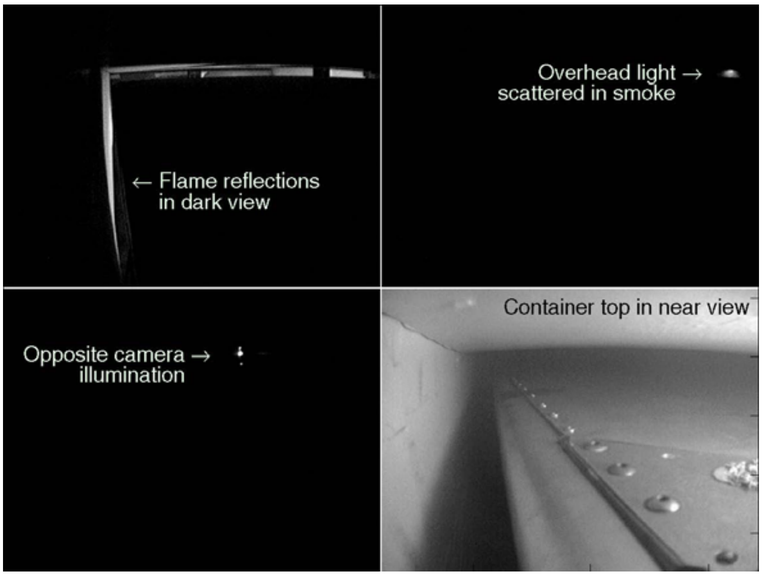


Fig. 3 Four views of a camera behind containers with different illumination

However, for a video-based detection system, the scene geometry and contents are critical. The scene should closely represent the actual application. For an aircraft cargo bay application, the fire test room should resemble an actual cargo bay, including cargo obstructions in the camera field of view. The tests should also retain the repeatability aspects of the EN-54 tests. Possible candidates for the testing of the CFVS included:

- Special testing aircraft
- A reconstruction of a cargo compartment
- A modified EN-54 test room

Testing in an aircraft has many disadvantages, e.g. high costs, limited test time, and restricted test options (no open fires and dust tests are permitted). Figure 4 is an image from a video recording of a smoke test in an A340-600 aircraft.
Tests in a reconstruction of a cargo compartment, such as the A340-500 cargo bay mock-up in Trauen, Germany, have the advantage that the geometry is very close to the actual cargo bay, Figure 5 shows the mock-up.

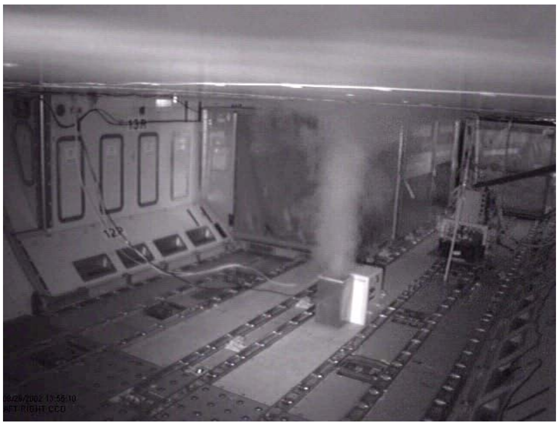


Fig. 4 Smoke generator test in A340-600 aircraft

Fig. 5 A340-500 cargo bay mock-up in Trauen

The main drawbacks of the Trauen mock-up are the difficult adaptation to a special compartment type, high construction effort, and the required space only for this application. Furthermore, no comparative EN-54 tests are possible because of the smaller volume of the mock-up, the uncontrollable environmental conditions, and the lack of required instrumentation. Because of the disadvantages listed above, the tests were performed in the fire detection lab of the University Duisburg-Essen, which is traditionally used for EN-54 tests.

Fire room configuration

The Duisburg fire lab exhibits an EN-54 like test cell with the option of changing the height of the cell by moving the ceiling in a wide range. Advantages of the Duisburg fire lab are controlled environmental conditions, a wide range of measurement possibilities, and a significant better probability for “repeatable” tests than other testing options. The fire room was modified so that it more closely resembled a cargo bay in the following ways (see Figure 6, Figure 7, and Figure 8):

- Aluminium side wall plates were hung from the ceiling to reduce the room width to that of a cargo bay. The side walls hung down 95 cm from the ceiling at a distance of 210 cm from the centerline of the fire room, emulating a cargo compartment width of 420 cm. To enhance the realism of the side walls, the plates were covered with DuPont Tedlar PVF Film as in an actual cargo bay.

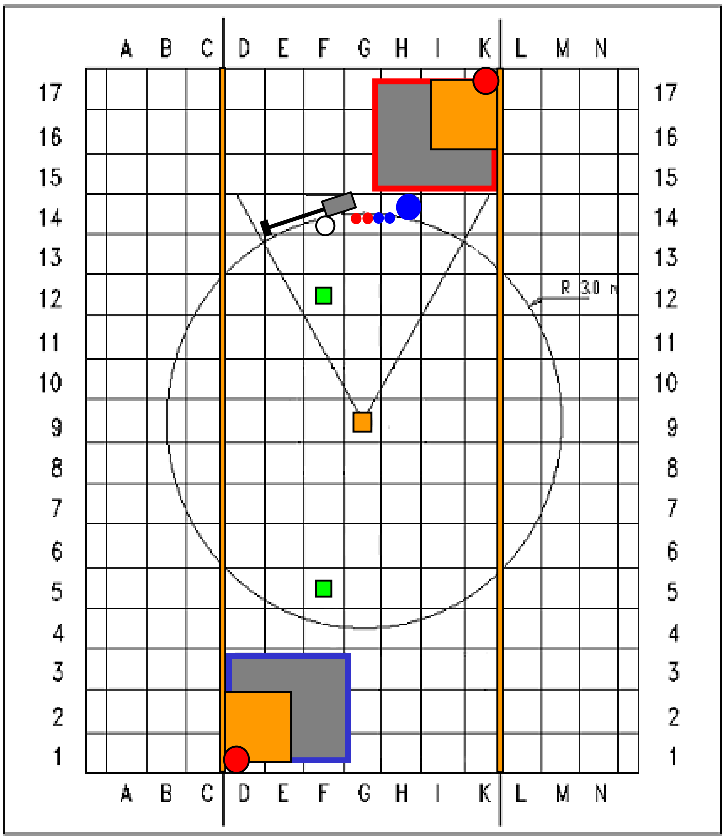


Fig. 6 Modified Duisburg Test Cell, top view

- A single 1 m² sheet metal plate covered with the cargo bay lining material was mounted on the ceiling near the cameras in order to provide realistic optical conditions near the cameras.
- Fire and non-fire sources were placed on a platform, so that the distance between the source and the fire room ceiling was 1.7 m, which is the floor to ceiling distance in a cargo bay. A platform was required to raise the source because the ceiling cannot be lowered closer than 2.87 m from the fire room floor.
- LD-3 cargo containers were placed in front of the cameras to limit the field of view to the gap between the top of the container and the ceiling. Both containers were set on platforms so that the gap between the container and the ceiling was in the worst case at a minimum value of 4.3 cm. The containers were located according to existing cargo loading standards.

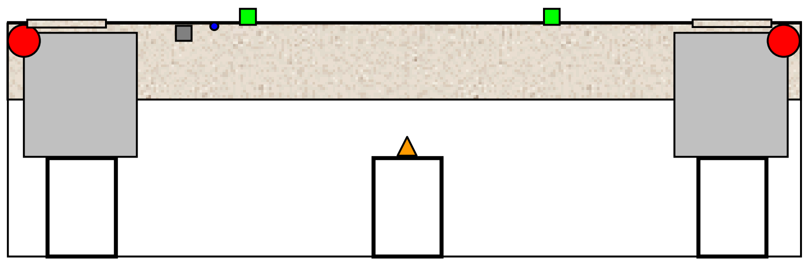


Fig. 7 Modified Duisburg Test Cell – Side View

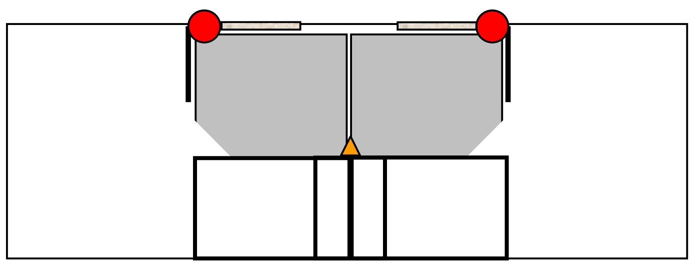
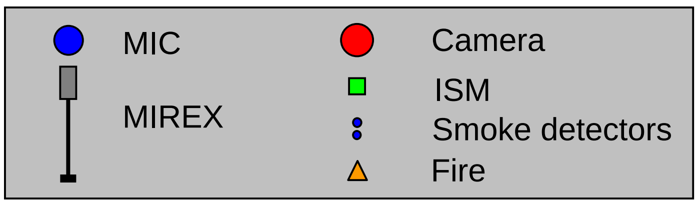


Fig. 8 Modified Duisburg Test Cell – Front View



- The test cell observation windows were covered so that outside light did not enter the test cell. In addition, the test cell lights were turned off during the tests.

Fire tests

A suite of fire sensitivity tests applicable to vision based fire detection systems was then developed by Goodrich Corporation and the Universität Duisburg-Essen. One objective was to scale down the standard EN-54 fire sensitivity tests [2][3] for the reduced volume of the modified test cell as described above. Fire and smoke tests were performed in the A340-500 cargo bay mock-up in Trauen and in Duisburg.

At the Duisburg Fire Detection Lab tests were performed in three major types of scenarios, see Table 1 [4]:

- Standard EN-54 test fires.
- Modified test fires without test cell modifications, but with camera obstructions by containers.
- Modified test fires with test cell modifications (for Forward, Aft, and Bulk compartment configurations), including camera obstructions by containers. The test cell was modified to more closely resemble an actual cargo compartment as mentioned before, and the test fire material was reduced to account for the reduced test cell volume.

		Modified test fire		**EN-54 test fire**	
TF	Material	Amount	Pan size	Amount	Pan size
1	beech wood	40 pieces	-	72 pieces	-
2	beech wood	16 pieces	-	30 pieces	-
3	cotton	54 wicks	-	108 wicks	-
4	polyurethane	2 mats	-	4 mats	-
5	n-heptane	120 g	12cm*12cm*2cm	650 g	33cm*33cm*5cm
6	alcohol	850 g	33cm*33cm*5cm	2300 g	50cm*50cm*5cm
7	decalene	75 g	10cm*10cm*2cm	170 g	12cm*12cm*2cm

Table 1 EN-54 and modified test fires

Even though the room geometries of both test cells (the reconstruction of a cargo compartment in Trauen and the Duisburg fire lab) are completely different, the results are comparable in terms of smoke density measurements when using a scaling factor. If smoke density (measured via the MIREX instrument) over time values measured in Duisburg (without side walls) are multiplied with a factor “3” the values are comparable with the Trauen results [5]. Figure 9 compares the Duisburg test cell and Trauen mock-up.

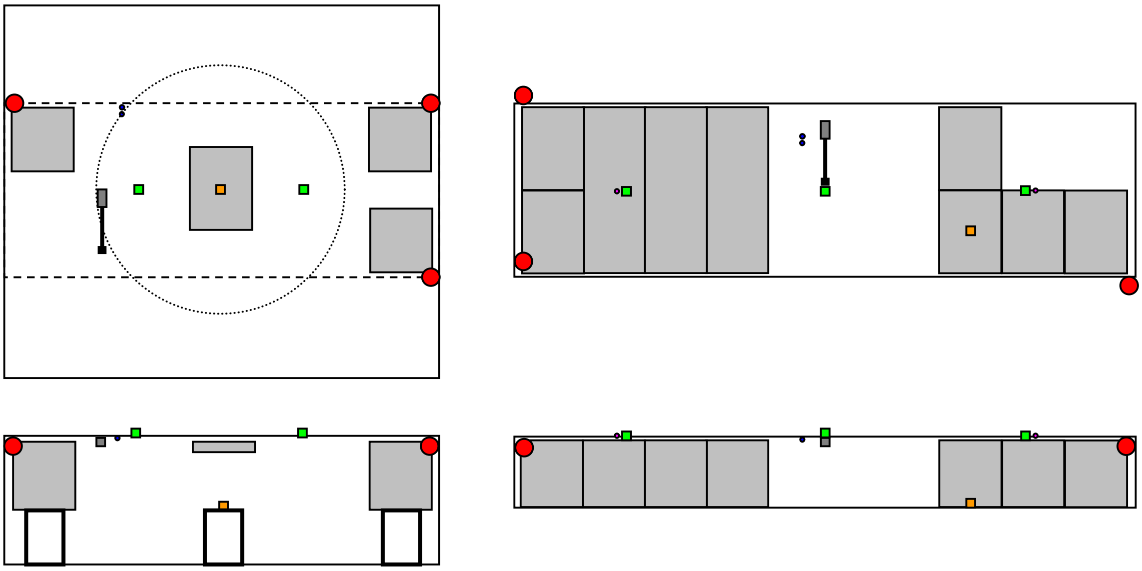


Fig. 9 Comparison of Duisburg top view (upper left), Trauen top view (upper right), Duisburg side view (lower left), and Trauen side view (lower right)

The Duisburg test cell volume was 293 m³ (10.5 m * 9.0 m * 3.1 m) and the Trauen mock-up volume was 103 m³ (15.0 m * 4.2 m * 1.71 m). Figure 10 compares smoke density values for TF2 runs at both locations and scaled values.

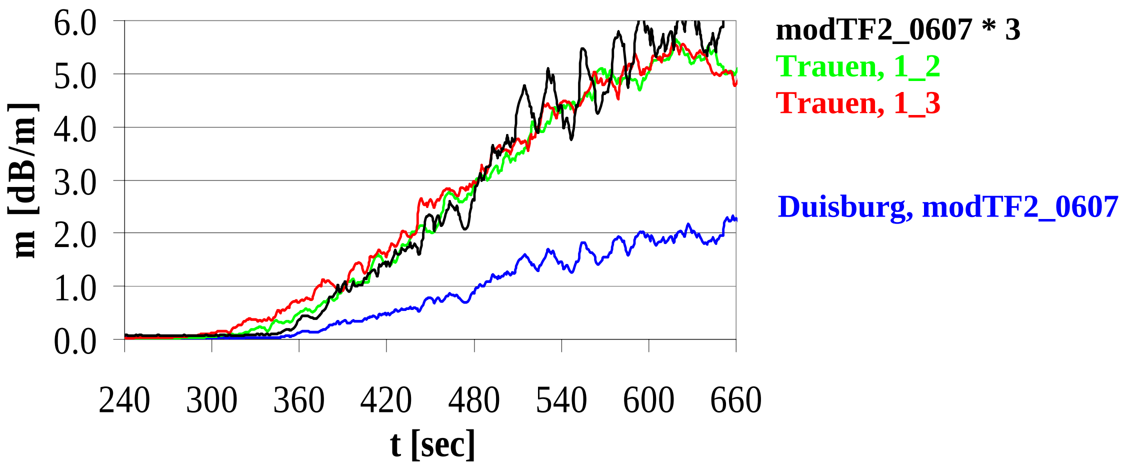


Fig. 10 MIREX values of modified TF2, measured in Trauen and in Duisburg (without side walls) and scaled values

Further tests with side walls in Duisburg show very good results with respect to the reconstruction of a cargo compartment in the Trauen - it is still a simple scaling factor to approximate the results from Trauen. A scaling factor of “1.5” shows a good approach to Trauen data bay (see Figure 11).

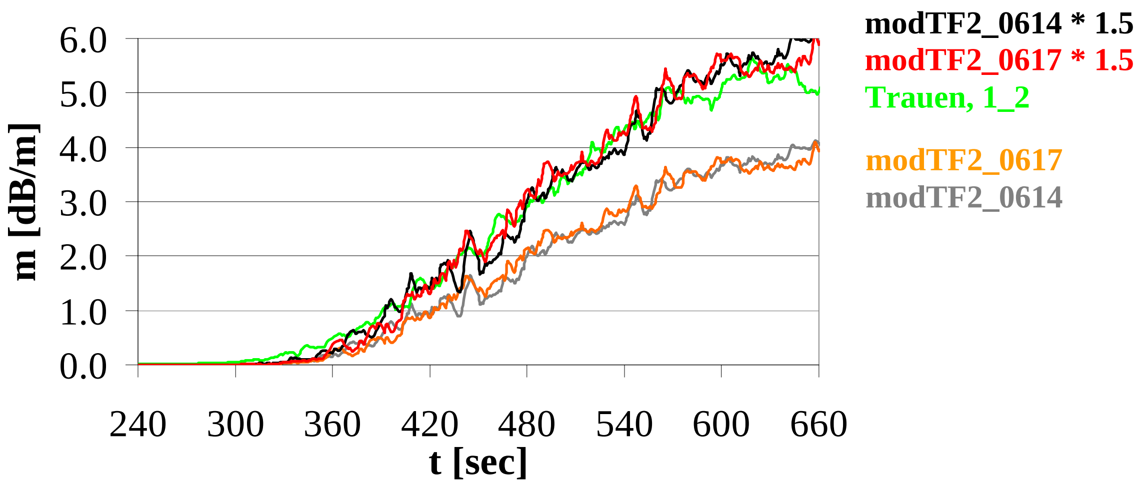


Fig. 11 MIREX values of modified TF2, measured in Trauen and in Duisburg (with side walls) and scaled values

Traditional smoke detectors were also part of the preliminary scaling experiments, and the smoke densities at which they alarmed were determined for each test fire type. Figure 12 shows the alarm time of a conventional smoke detector and a CFVS alarm.

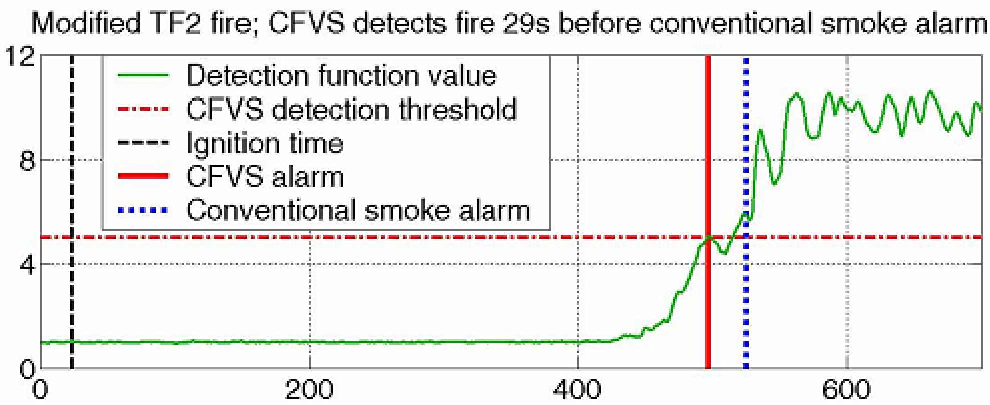


Fig. 12 Modified TF2 fire with alarm times

The CFVS detected the modified TF2 fire 29 sec before the conventional smoke alarm which is in line with the design goals The CFVS was designed to detect the test fires at a lower smoke density than the traditional smoke detectors.

Dust tests

In addition to fire tests, non-fire tests with dust were set-up and performed. Dust is known to cause problems with optical smoke detectors and not only in cargo bays. Depending on the dust type and the dust production it may look similar to smoke on video. Thus the discrimination of dust and smoke in video-based systems is a challenge in its own. Therefore special consideration was given to dust tests and measures in order to provide a high degree of repeatability.

The objective of these dust tests is not to investigate dust properties against smoke or to develop special dust-related image features to properly identify dust under some predetermined cases. The objective is to set a combination of thresholds and conditions so any aerosol, including smoke, dust and fog, will not be declared by the CFVS as smoke and processed for subsequent validation and final confirmation unless those detection thresholds are crossed. If such thresholds are crossed, dust will be then perceived by the CFVS as smoke.

The dust tests used the test cell configuration modified to mimic a cargo bay, as described above. Figure 13 shows the set-up for the dust test. The key factors in the dust tests included the type of dust, the rate of dust introduced into the test cell, the amount of time that dust was generated, and the location of the dust generator.

Dust is typically defined as *"small solid particles, conventionally taken as those particles below 75 µm in diameter, which settle out under their own weight but which may remain suspended for some time"* [6]. Standardized dust particles are designated in several groups [7] and two of them were used for testing in Duisburg fire lab:

- A1 dust: Ultrafine, dust particles with nominal size of 0-10 µm
- A2 dust: Fine, dust particles with nominal size of 0-80 µm

The small particles in these dusts remain airborne longer than large particles and are more likely to be detected as smoke. They also are close to the particle sizes found in wood smoke, which makes it very difficult for detection systems to distinguish between smoke and dust.

A dust generator was used to introduce dust into the test chamber. The generator adds the dust to a compressed air stream which is then directed by a nozzle into the test cell. The dust was expelled at a constant rate of 140 g/s. The dust nozzle was directed vertically towards the ceiling. By adjusting the compressed air pressure and the height of the dust generator, it was possible to create a dust cloud just below the ceiling. This put the dust cloud directly into the CFVS field of view. This type of dust generation is also analogous to the smoke generation of the test fires described above.

Fig. 13 Set-up for the dust test

In the test fires, the smoke rises in a vertical stream and then forms a cloud beneath the ceiling. Making the dust generation mimic the smoke generation is a challenging false alarm immunity test for the CFVS.

The total amount of dust injected into the test cell was controlled by the on-time of the dust generator. The on-time was used as the key metric for determining a system's immunity to dust. Dust levels in the test cell were measured with a separate particle counter, whose inlet tube was placed in the ceiling of the test cell. The particle counter values were used to verify that the dust generation was valid. Two examples of two minutes of dust generation are shown in Figure 14, dust tests were considered valid if the max. particle counter value is greater 9000 [8].

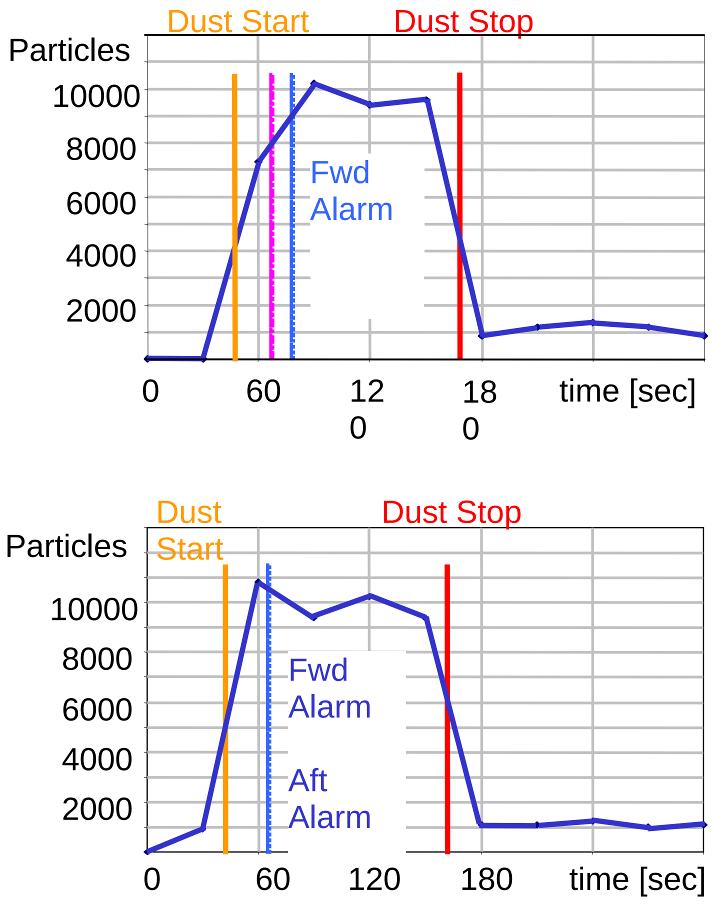
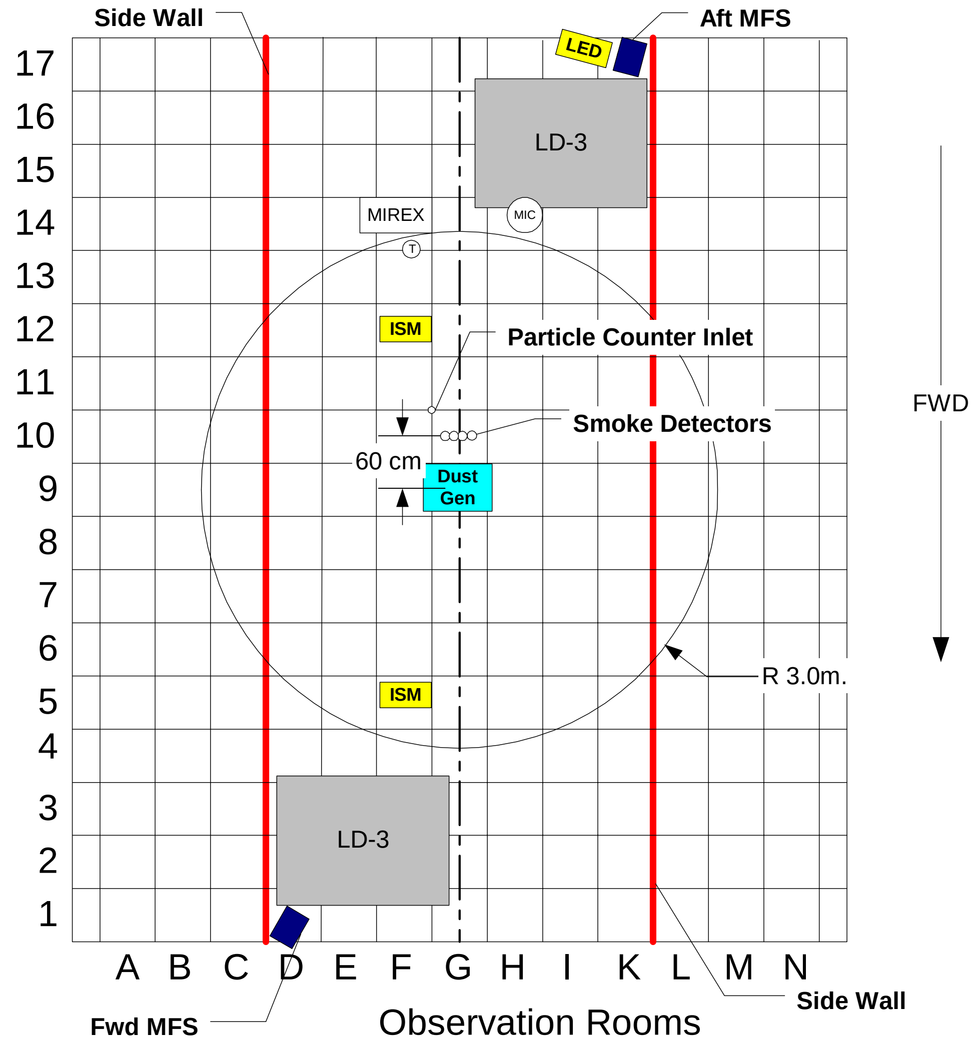


Fig. 14 Two examples of particle counter values during a dust experiment

In preliminary testing, the dust generator was placed in several locations in the attempt to satisfy two objectives:

1. Subject the traditional smoke detectors and the CFVS to the same dust environment.
2. Determine the amount of dust generator on-time to trigger a smoke alarm from the traditional smoke detectors.

The preliminary tests led to the definition of the CFVS dust-immunity tests. Figure 15 is a top view of the test chamber for the Forward and Aft bay configuration tests. Figure 16 is the same view for the Bulk bay configuration tests.



Fig, 15 Test cell set-up for Forward and Aft bay dust tests

In the Forward and Aft bay configuration, the test cell includes sidewalls and reflective plates, as did the modified test cell for the test fires. The dust generator was placed on a platform in the center of the test cell, in the same location as the test fire source.

LD-3 cargo containers on platforms limited the view of the video cameras to the 4.3 cm gap between the containers and the ceiling.

In the Bulk bay configuration, the dust generator was moved closer to the lone video camera in response to the smaller size of the Bulk compartment. The camera field of view was obscured by LD-3 containers.

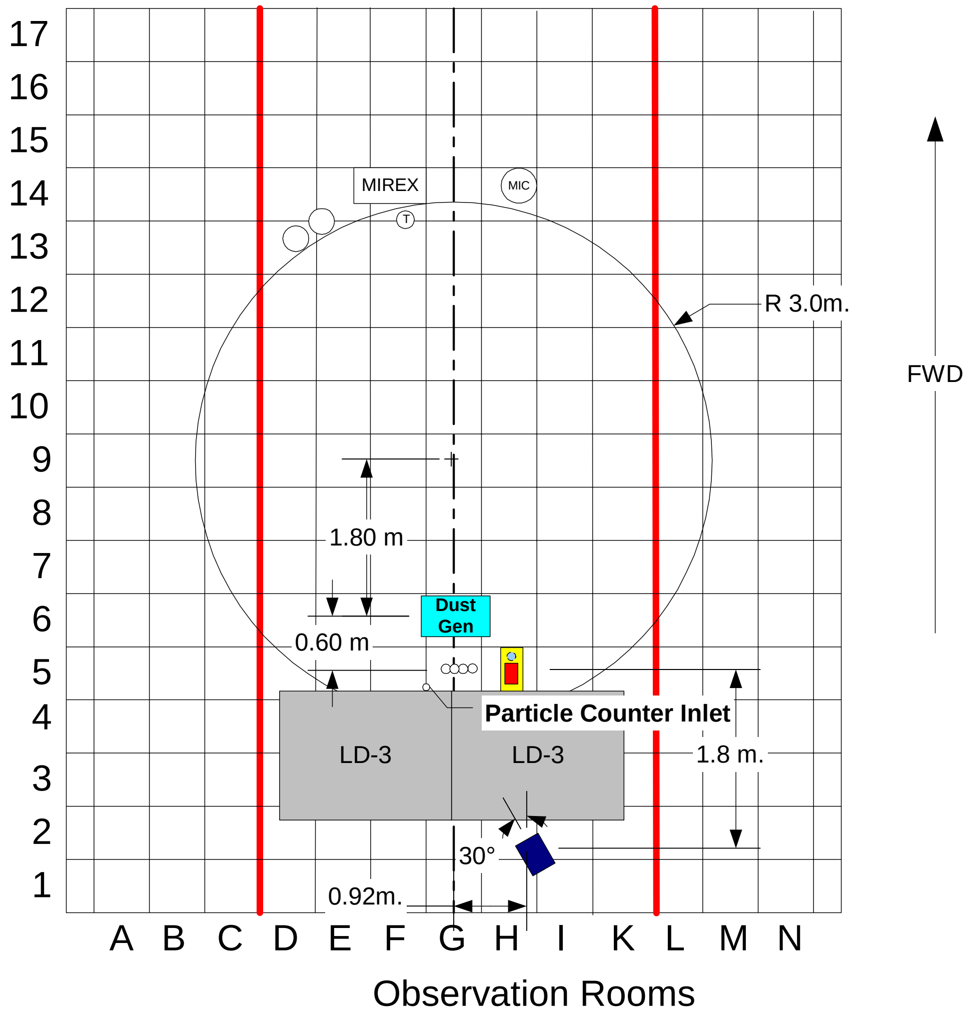


Fig. 16 Test cell set-up for Bulk bay dust tests

The main CFVS dust-immunity requirement is that the CFVS must not indicate a smoke alarm for a given time after the start of dust generation.

That critical time was far beyond the time at which a traditional smoke detector would issue a false alarm. After finishing the dust tests smoke detection thresholds had to be set in such a way that dust does not cross those thresholds but all test fires do. Figure 17 shows smoke detector alarm times for dust experiments with different dust types (dust A1 and A2) for different cargo compartment types (Aft bay and Bulk bay) [8].

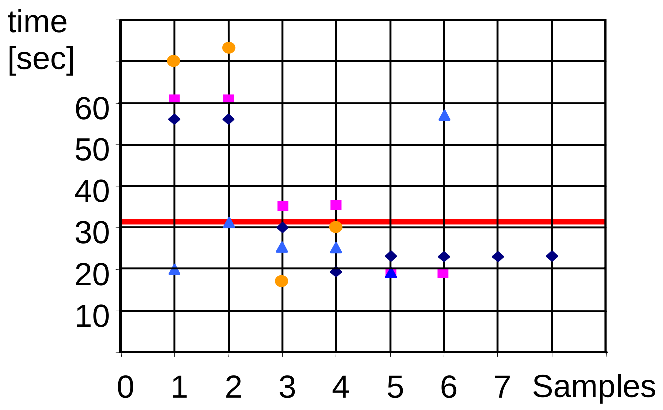


Fig. 17 Smoke detector alarm times for dust experiments, time after dust generation start [sec.]

Figure 18 shows results of a dust test. It can be seen that the conventional smoke detector had a false alarm 19 seconds after start of dust generation, the CFVS could diagnose the non-fire case, so iIt was possible to unconfirm the primary system's alarm.

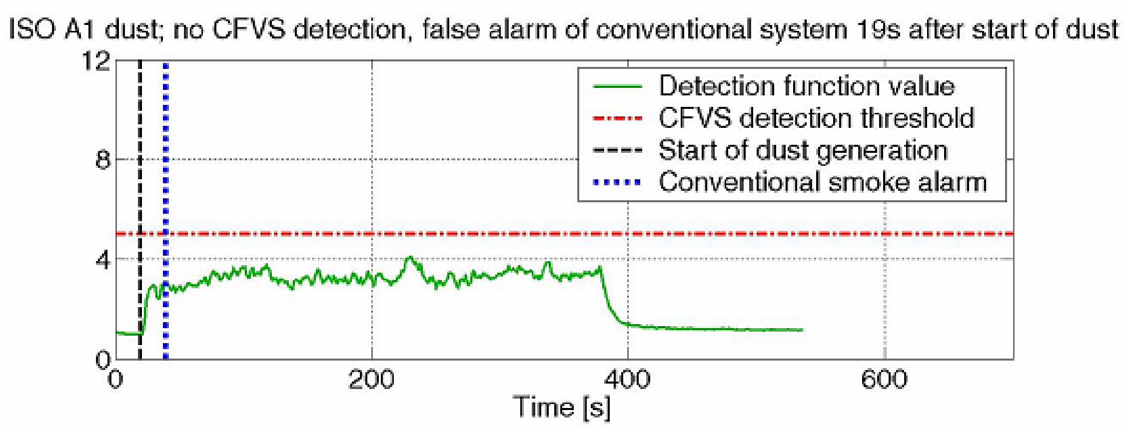


Fig. 18 ISO A1 dust test with a false alarm of a conventional smoke detector

Conclusions

The existing testing guidelines and standards for qualification of current smoke detection systems were formulated mainly to address the case of traditional detection technologies. It was necessary to develop a suite of fire sensitivity tests, non-fire tests with dust and test room modifications applicable to vision based fire detection systems. Modified tests with room modifications in the Duisburg fire lab show good match with tests performed in a cargo mock-up.

Recordings of point smoke detectors, video sensors, and reference measurement devices were obtained in exhaustive test series in the Duisburg fire lab. Data were then used in course of the algorithm development of the CFVS by Goodrich Corporation, and for defining the performance criteria.

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