DETERMINATION OF SMOKE QUANTITIES TO BE USED FOR SMOKE DETECTION PERFORMANCE GROUND AND FLIGHT TESTS

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Abstract

For obtaining aircraft certification it is mandatory to show compliance with the applicable airworthiness requirements. For cargo smoke detection systems, e.g. JAR 25.0858(a) requires "visual indication to the flight crew within one minute after the start of a fire". Smoke detection performance ground and flight tests must be conducted to demonstrate compliance with the rules.

Although the given time for smoke detection is clearly specified (i.e. 60 seconds), the quantity of (simulated) smoke for showing compliance is not. An approach will be presented for determination of applicable smoke amounts. Test results are given for validation of the approach.

1 Introduction

In the context of Airbus A318 certification the smoke generation method (paraffin oil smoke generator, refer to Fig. 1) used by Airbus was discussed with Airworthiness Authorities. The method was accepted but it was made clear that smoke quantities needed further explanations for the upcoming certification projects, i.e. for the certification of the Airbus A380.

This paper summarizes how the smoke quantities used for ground and flight tests within A380 lower deck cargo compartments were justified to the Airworthiness Authorities. For simplicity reasons, only the unventilated compartment is considered.

Fig. 1: Development Ground Test in A300 Freighter

1.1 Background

The following constraints are to be taken into account for the determination of smoke amounts to be used for certification testing:

1. Aerospace Standard AS 8036 ("Cargo Compartment Fire Detection Instruments," dated April 1, 1985) requires the sensitivity of optical smoke detectors to lie in the following range:

Required Alarm Threshold Setting (Light Obscuration)	
% / ft	% / m
4 - 40	12.5 – 81

Table 1: Optical Smoke Detectors setting according to AS 8036

2. Smoke Detection Test Guidelines according to AC 25-9A state that "A smoldering fire producing a small amount of smoke in conjunction with the applicable detection time has been selected as a fire or failure condition that could be detected early enough to ensure that the fire and smoke procedures would be effective."

The challenge is therefore to find an applicable smoke quantity that fulfils both point 1 and 2.

2 Airworthiness Authorities' Approaches

Efforts for determination of smoke amounts to be used for certification testing have been going on for decades.

2.1 Smoke Powder

In FAA technical report FAA-ADS-73 (Characteristics of Fire in Large Cargo Aircraft, March 1966) a mixture of each 50% potassium chlorate and lactose is proposed to be used for certification tests on smoke detection installations. The following pros and cons of this powder compared to other methods are known:

Advantages:

- real combustion process
- less oil vapours
- less staining fluids

Disadvantages:

- difficult handling as powder is classified in the same class as gun-powder
- poor reproducibility
- high temperature generation during burning process
- sputtering during burning process
- corrosive by-products
- toxic gases

This powder was used within all Airbus aircraft programs until mid of the nineties. For the above-mentioned disadvantages, in particular the heavy sputtering, a paraffin oil smoke generator was then developed (ref. to chapter 3.1).

2.2 "Burning Suitcase"

In 1998, a video of a burning suitcase was distributed with FAA Transport Airplane Directorate Policy Letter TAD-97-004. This letter was released to all FAA Aircraft Certification Offices with the intention of providing "visual guidance" for smoke detection. Fig. 2 depicts a snapshot of this video 30 seconds after first smoke was visible.

Fig. 2: Snapshot of Burning Suitcase Video

The disadvantage of the "burning suitcase video" was that there was no physical data (e.g. light obscuration) available. Moreover, the fire scenario itself was not reproducible at all and the approach was finally abandoned.

2.3 Flaming Resin Block

To overcome this lack, FAA Technical Center has developed a different smoke source for lab test application: The “flaming resin block” is composed of several plastics and poses a reproducible fire scenario. It can be detected by optical smoke detectors as well as by fire-/ smoke detectors using other technologies (e.g. gas sensors). Furthermore, it was developed to produce a comparable smoke quantity to the “burning suitcase”.

Fig. 3: Flaming Resin Block (10x10x1 cm^3)

3 Airbus Approach

3.1 Paraffin Oil Smoke Generator

The development of the paraffin oil smoke generator put focus on being able to generate different amounts of smoke corresponding to different amounts of fuels like smoke powder (refer to chapter 2.1) in a reproducible way. E.g. Program 5 corresponds to the smoke amount produced by 60g of smoke powder whereas Program 6 corresponds to a smoke amount generated by 120g.

Airbus has been using this smoke generator for all recent certification ground and flight tests. The functioning principle is based on pre-heated paraffin oil that is directed towards a heated deflection plate directing the smoke upwards. This heating and deflection is necessary to simulate the “buoyancy”-effect (i.e. rise-tendency of real smoke). The functioning principle is illustrated in Fig. 4.

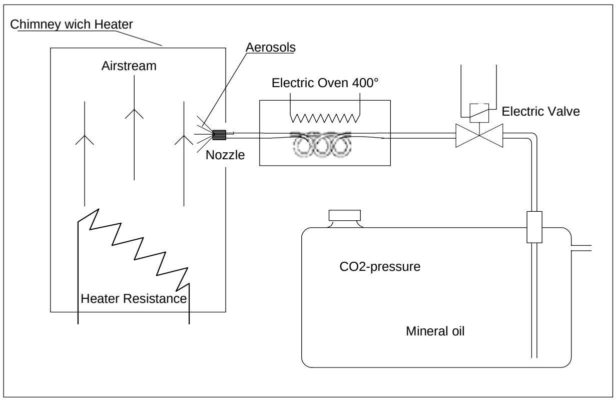


Fig. 4: Paraffin Oil Smoke Generator Functioning Principle

3.2 Determination of Smoke Amounts

The following inputs were to be taken into account for justification of the smoke amounts to be used for certification testing:

- Light obscuration is used as a reference criterion for optical smoke detectors.
- 4 %/ft (i.e. 12.5 %/m) light obscuration is the most sensitive alarm threshold setting to be in line with AS 8036 (see chapter 1.1).
- With an increase of heat emission the effect of buoyancy (i.e. the tendency of smoke to go upwards) is amplified, therefore the reference criterion shall be measured at ceiling level.

Based on these points, the following “cornerstones” were defined for the determination of smoke amounts to be obtained through a mock-up test campaign. A smoke generator setting was to be determined, in which

1. the light obscuration at ceiling level was in the range of 12.5 % / m (4 % / ft) after 30 s and
2. the location of the measured (reference) light obscuration was at one third of the compartment length (applicable for wide body/long range aircraft like A380 or A340)

This procedure is illustrated in Fig. 5.

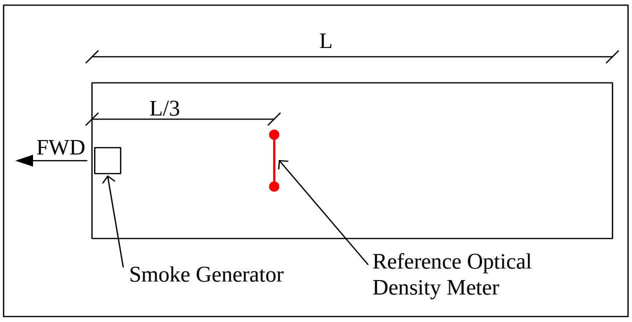


Fig. 5: Top view of cargo compartment

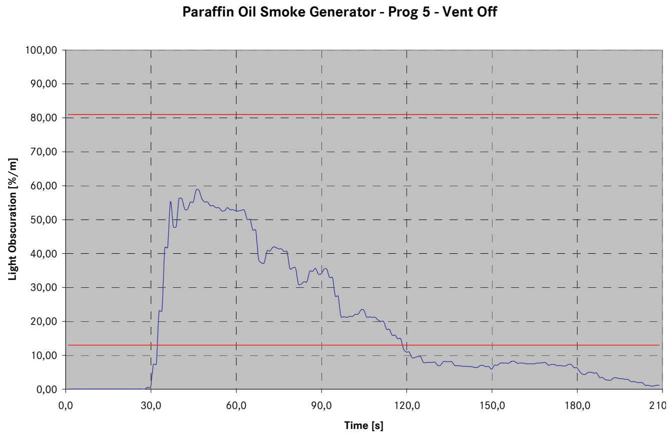
To thus validate the smoke amounts generated by the paraffin oil smoke generator, a mock-up test campaign was conducted beginning of 2005. During this campaign, the smoke generator was also compared to the flaming resin block smoke (refer to chapter 2.3).

4 Mock-Up Test Campaign

The tests were conducted in a mock-up of the same size as the Airbus A380 FWD cargo compartment (refer to Fig. 6).

Fig. 6: Snapshot taken 30s after smoke emission by paraffin oil smoke generator (orange-coloured, center/bottom), the optical density meter can be seen in the center

The obtained results are depicted in Fig. 7 - 9.



AS 8036 limits

Light obscuration (measured by optical density meter in %/m)

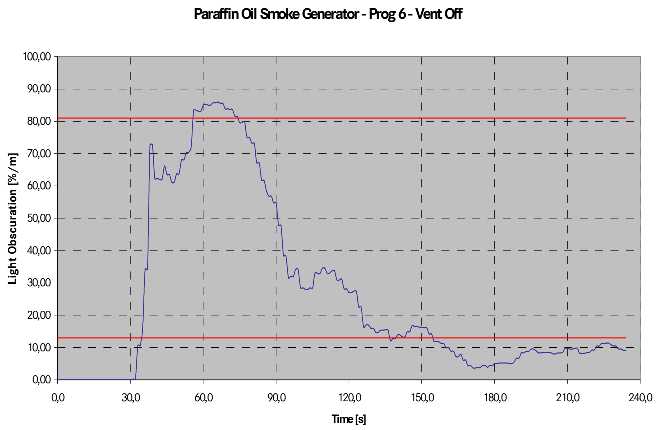
Fig. 7: Smoke density for Program 5

The following properties are apparent:

- Light obscuration of 13%/m reached after 32s
- Maximum light obscuration of 56%/m reached after approx. 48s
- Upper limit of AS 8036 not reached

To summarise, smoke generator setting 5 is in accordance with Airbus proposal but smoke detectors set to the least sensitive level of AS 8036 would not trigger an Alarm

Therefore, in the next test Program 6 was used. The results are depicted in Fig. 8.



AS 8036 limits

Light obscuration (measured by optical density meter in %/m)

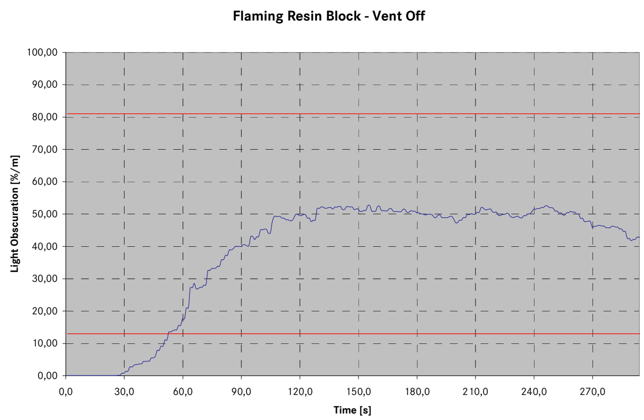
Fig. 8: Smoke density for Program 6

The following properties are apparent:

- Light obscuration of approx. 13%/m reached after 34s
- Maximum light obscuration of 85%/m reached after approx. 65s
- Upper limit of AS 8036 reached

To summarise, smoke generator setting 6 is in accordance with Airbus proposal and smoke detectors set to the least sensitive level of AS 8036 would trigger an Alarm.

For reference, the test campaign was concluded by conduction of tests with the flaming resin block. The results are given in Fig. 9.



AS 8036 limits
Light obscuration (measured by optical density meter in %/m)

Fig. 9: Smoke density generated by the flaming resin block

The following properties are apparent:

- Light obscuration of approx. 13%/m reached after 52s
- Max. smoke density of approx. 50%/m maintained over 3 minutes
- Upper limit of AS 8036 not reached

Compared to the results obtained with smoke generator in program 5 and 6, the signal increase starts at the same time but is followed by a slower signal increase. The maximum reached light obscuration corresponds to approx. 54 %/m, which is well beyond the minimum allowed level of AS 8036 qualified smoke detectors and corresponds quite exactly to that level reached by the smoke generator Program 5 (56%)

To summarise, the dynamic is lower whereas the smoke amount over three minutes is higher than that generated by smoke generator program 5 and 6.

5 Summary and Conclusion

It was shown in chapter 4 that the smoke quantity produced by the paraffin oil smoke generator with the given settings is well between the limits given in AS 8036. Furthermore, it was shown that the smoke generator is in line with the Airbus proposal presented in chapter 3.2.

Additionally, the smoke amounts generated by the smoke generator were compared to the latest reference test fire scenario developed by FAA Technical Center. The “smoke-signatures” resemble each other for both smoke types, although there are slight differences with respect to the dynamic behaviours.

Finally, the smoke generator that was developed to resemble the smoke powder fire scenario (refer to chapter 2.1) on the one hand and the flaming resin block that was developed to resemble the burning suitcase (refer to chapter 2.2) on the other hand, provide similar smoke signatures.

For all these reasons, it can be concluded that all certification guidelines and standards are fulfilled by the smoke generation method for certification ground- and flight-testing presented in this paper.