Applied Science
Ingenieurbüro Dieter Scholz

Seevering 53
D - 21629 Neu Wulmstorf

Aircraft Fire Protection

Dieter Scholz

April 2006

Report

prepared for

Minimax GmbH & Co KG

Industriestraße 10/12
D - 23840 Bad Oldesloe

Table of Contents

Abbreviations

AC	Advisory Circulars
ACJ	Advisory Circular Joint
AMJ	Advisory Material Joint
APU	Auxiliary Power Unit
ATA	Air Transport Association of America
BITE	Built-In Test Equipment
CCF	Common Cause Failures
CS	Certification Specifications
DMC	Direct Maintenance Costs
DOC	Direct Operating Costs
EASA	European Aviation Safety Agency
ECS	Environmental Control System
ETOPS	Extended range Twin-engine OPerationS
FAA	Federal Aviation Administration
FAR	Federal Airworthiness Requirements
FH	Flight Hour
FMEA	Failure Mode Effect Analysis
FMECA	Failure Mode Effect and Criticality Analysis
FTA	Fault Tree Analysis
FTRR	Failure To Removal Ratio
ICAO	International Civil Aviation Organisation
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements
LED	Light Emitting Diode
MDO	Multidisciplinary Design Optimization
MEL	Minimum Equipment List
MMEL	Master Minimum Equipment List
MTBF	Mean Time Between Failures
MTBUR	Mean Time Between Unscheduled Removals
MTTR	Mean Time To Repair
OEW	Operational Empty Weight
RAT	Ram Air Turbine
RBD	Reliability Block Diagram
SAE	Society of Automotive Engineers
ZSA	Zonal Safety Analysis

More abbreviations and abbreviations specific to Airbus aircraft are provided in
http://www.haw-hamburg.de/pers/Scholz/materialFS/Abkuerzungen.pdf

1 Setting the Scene

This report tries to give an introduction to the topic *fire protection* (Feuerschutzanlagen) on aircraft.

Already in the *beginning of flight*, aircraft got lost through fires. Possible causes of a fire were mostly the fuel system or the electrical system. In 1925 most aircraft were equipped with some kind of fire protection equipment. Fire protection equipment was – for obvious reasons – of special importance for the air forces. In Germany, also *Minimax* of Neuruppin was one of the suppliers to the German Luftwaffe (**Ruff 1989**).

Fire protection on aircraft is of particular importance, because once the aircraft is airborne, any fire needs to be taken care of with *on board equipment*. Particularly during flights over remote areas, a fire needs to be kept under control for a relatively long time before an emergency landing on an alternate airport may be achieved. Furthermore, an aircraft includes *areas* that are *not accessible during flight*. In these areas of the aircraft, remote sensing and (semi-)automatic equipment is required.

Fire protection on aircraft is broken down into
- *detection* (Feuerwarnung) and
- *extinguishing* (Feuerlöschung).

Main areas of fire protection on an aircraft are
- the engines (Triebwerke)
- the auxiliary power unit (Hilfstriebwerk)
  (mostly installed in the tail cone of aircraft, the cargo compartment).

Other areas of the aircraft that may be equipped with a fire protection system are
- the cargo compartment (Frachtraum)
- the landing gear bay (also called: wheel well) (Fahrwerksschacht)
- the avionic compartment
- areas that are exposed to bleed air (Zapfluft) from the engines for anti icing (Enteisung) or heating purposes
- areas of the aircraft cabin including
  - lavatories (Toiletten)
  - crew rest compartments.

This introduction only takes account of fire protection on civil transport aircraft. "Fire Protection" is one of many systems on the aircraft.

Layout of the Report

Chapter 2	gives an introduction to aircraft systems in general. The aim of this Chapter is to make the reader familiar with the basic concepts of aircraft systems: safety/reliability, certification, maintainability, mass, power, costs and documentation.
Chapter 3	provides aircraft fire protection fundamentals.
Chapter 4	shows some more details of fire detection and extinguishing using the Airbus A321 as an example.
Chapter 5	addresses some special issues that are of interest for Minimax in 2006.

2 Introduction to Aircraft Systems

2.1 Aircraft Systems General

What are Aircraft Systems?

Broadly speaking, an aircraft can be subdivided into three categories:

1. the airframe (the aircraft structure)
2. the power plant (the engines)
3. the aircraft systems (the equipment).

This section deals with the last of these categories. Aircraft systems comprise thus all these many mechanical, electrical, and electronic items, devices and components, which are installed in an aircraft for the various purposes.

People usually take well account of the airframe and the power plant: The airframe provides the aircraft with its (relative) rigidity. Furthermore it enables the generation of lift through its aerodynamic shape. With a glider you can get away without a power plant. But in order to maintain (weather independent) sustained level flight, a power plant is necessary to produces thrust to overcome the drag.

The uninitiated observer might conclude that with airframe and power plant we already have all we need. This however is not true. Even the earliest aircraft needed more. Necessary were some means to steer the aircraft (*flight controls*) and to handle it on the ground (*landing gear*). This explains, why these aircraft systems also today play a key role among the many aircraft systems and have to be considered already in the very early stages in aircraft design. Obviously also a *fuel system* was needed from the beginning of the history of powered flight. With aircraft flying longer distances *navigation* and *communication systems* became important; with aircraft flying higher and taking passengers on board, cabin systems like *air conditioning* and *oxygen systems* were introduced.

Those readers who have not been familiar with the term "aircraft systems" should by now have an idea what aircraft systems are. For the insider a much more rigorous definition of the term is necessary and will be provided further down.

Significance of Aircraft Systems

The mass of the aircraft systems accounts for 1/3 of the aircraft's empty mass. Similarly, aircraft systems have a high economical impact: More than one third of the development and production costs of a medium range civil transport can be allocated to aircraft systems – and this ratio can even be higher in case of military aircraft. In the same proportion, the price of the aircraft is driven by aircraft systems. Aircraft systems account roughly for one third of the Direct Operating Costs (DOC) and the Direct Maintenance Costs (DMC).

Historical Trends

Since the 1960th stability in aircraft silhouettes and general design concepts can be observed. Nevertheless, remarkable progress has been achieved since that time: In the same way as aerodynamics, structures, and power plants have been optimized, also aircraft systems have been gradually improved in economics, reliability, and safety. This has been made possible by a constant evolution and optimization through in service experience, research, and development and also by employing new technologies.

Probably the most important impact to the changes has been made by digital data processing. Today, computers are part of almost every aircraft system of larger aircraft. Furthermore, computers play a key role in the design and manufacturing process of aircraft systems. Looking at current developments, it can be concluded that the evolution of aircraft systems has not come to an end yet. Modern achievements in computer technology will further make their way into the aircraft.

Striving for improved safety, economics, and passenger comfort will demand even more sophisticated technologies and complexity. The airlines show some reluctance to accept the ever-increasing complexity for the reason that trouble shooting the aircraft does not get easier. Aviation industry has taken on an approach that technology has to "buy its way onto the aircraft" – i.e. only if new technologies can prove their overall benefit they will be a candidate in a new aircraft design.

It should also be noted that the separate tasks of the structure, the engines, and the systems are being more and more integrated to handle the tasks together. Here are some examples:

- Electronic flight control systems stabilize a fighter aircraft with an unstable layout or stabilize aircraft structural or rigid body modes.
- A gust load alleviation system as part of the flight control systems helps to reduce the design loads for the wing structure.
- A highly reliable yaw damper system enables the aircraft to be built with a fin, which is smaller than would otherwise be required.
- Engine parameters are changed in accordance with air conditioning demands.

To achieve an overall optimum in aircraft design it is no longer possible to look at the structure, the engines, and the aircraft systems separately. Today's challenge lies in the task to optimize the aircraft as a whole by means of Multidisciplinary Design Optimization (MDO).

The Industry

Aircraft systems are defined by the aircraft manufacturer. This takes commonly place in joined teams with engineers from specialized subcontractors. The subcontractors work on the final design, manufacture the system or component and deliver their parts to the aircraft manufacturer's final assembly line. The trend is for aircraft manufacturers to select major subcontractors who are made responsible for designing and manufacturing a complete aircraft system. These subcontractors may even become risk sharing partners in the aircraft program. Aircraft are maintained by dedicated maintenance organizations. Maintenance is done on aircraft and off aircraft. Off aircraft maintenance is performed on aircraft components in specialized shops.

2.2 Definitions

The term *system* is frequently used in engineering sciences. In thermodynamics e.g. a system is characterized by its defined boundary. The definition of the term system with respect to aircraft is a little more specific. The World Airlines Technical Operations Glossary (WATOG) defines:

System:	A combination of inter-related items arranged to perform a specific function. (**WATOG 1992**)

Subsystem:	A major functional portion of a system, which contributes to operational completeness of the system. (**WATOG 1992**)

The World Airlines Technical Operations Glossary also gives an example together with further subdivisions of the system and subsystem:

- system : auxiliary power unit
- subsystem : power generator
- component : fuel control unit
- subassembly : valve
- part : seal

Note that these definitions are taken out of the connotation of civil aircraft. With respect to military aircraft, people rather talk about *aircraft subsystems*. In the example above, the auxiliary power unit would hence be considered a subsystem.

When dealing with aircraft systems all categories of aircraft would need to be considered. ICAO defines:

Aircraft:	Any machine that can derive support in the atmosphere from the reaction of the air. (**ICAO Annex 2**)

Aircraft category:	Classification of aircraft according to specified basic characteristics, e.g. aeroplane, glider, rotorcraft, free balloon. (**ICAO Annex 1**)

Combining the above definitions, a definition for aircraft systems may read:

Aircraft System:	A combination of inter-related items arranged to perform a specific function on an aircraft.

This section specifically deals with aircraft systems on powered heavier-than-air aircraft i.e. on aeroplanes. Although aircraft systems of gliders, rotorcrafts, and free balloons have to take account of the specifics of the aircraft category in question, they are otherwise not fundamentally different from aircraft systems on aeroplanes.

2.3 Breakdown

Aircraft systems are distinguished by their function. It was common practice in civil aviation to group aircraft systems according to Specification 100 of the Air Transport Association of America (ATA) (**ATA 100**). Recently **ATA 100** has become part of the new ATA iSpec 2200 (**ATA 2200**). This has introduced also minor changes and updates to the definitions of aircraft systems. Both specification's aim is to thoroughly structure aircraft documentation. Accordingly, aircraft equipment is identified by an equipment identifier consisting of three elements of two digits each. The identifier 29-31-03 points to system 29, subsystem 31 and unit 03. The aircraft systems – or in ATA-terms: *airframe systems* – are listed in Table 12.1.1 together with their system identifiers. It is common practice to refer just to the system identifier *ATA 28* instead of referring to the "fuel system". Furthermore it is often referred to *Chapter 28* because chapter 28 is allocated to the fuel system in any aircraft documentation showing ATA-conformity.

Autopilot, communications, navigation, and indicating/recording systems (ATA 22, 23, 34, 31 [44, 45, 46]) are electronic systems, know in aviation as *avionic systems* and are characterized by processing information (compare with **SAE 1998**).

Other systems provide fuel, power, and essential comfort to crew and passengers. These non-avionic systems are the *general* or *utility systems*. Today, there is an increase in the number of electronic control units within the utility systems; nevertheless, the primary purpose of these systems remains some kind of energy transfer. (**Moir 2001**)

Secondary power systems comprise the non-propulsive power generation and transmission. They include electrical power, hydraulic power, pneumatic, and auxiliary power (**SAE 1998**) (ATA 24, 29, 36, 49). Secondary power systems provide power to other aircraft systems.

The *environmental control system* (ECS) is an engineering system, which will maintain the immediate environment of an organism within defined limits of temperature, pressure, and gaseous composition suitable for continuance of comfort and efficiency (**AGARD 1980**). The air conditioning system and the oxygen system (ATA 21, 35) are assigned to these tasks.

Table 2.1 Aircraft systems (**ATA 2200**)

identifier	name of system
21	air conditioning
22	auto flight
23	communications
24	electrical power
25	equipment / furnishings
26	fire protection
27	flight controls
28	fuel
29	hydraulic power
30	ice & rain protection
31	indicating / recording systems
32	landing gear
33	lights
34	navigation
35	oxygen
36	pneumatic
38	water / waste
44	cabin systems [a]
46	information systems [a]
49	airborne auxiliary power
50	cargo and accessory compartments [a]

a Aircraft systems newly defined in ATA 2200.

Also other terms are loosely coined. Examples are these:

Hydraulic systems comprise all systems that apply hydraulic power. In general, these are hydraulic power, flight controls, and landing gear (ATA 29, 27, 32).

Electric systems comprise all systems that apply electric power. In general, these are electric power (ATA 24) and all systems with major electrical consumers. Electrical systems are characterized by electrical power generation, distribution and consumption and have to be distinguished from avionic systems.

Pneumatic systems comprise all systems that apply pneumatic power. In general, these are pneumatic and other systems with pneumatic components (ATA 36, 21, 30).

According to a general understanding at Airbus, *cabin systems* comprise all systems with an impact on the cabin of the aircraft and hence with an influence on the passenger (ATA 21, 25, 35, 38 and partially 23, 26, 31, 33). Note: Following **ATA 2200**, "Cabin Systems (ATA 44)" are defined as "Those units and components which furnish means of entertaining the passengers and providing communication within the aircraft and between the aircraft cabin and ground stations. Includes voice, data, music and video transmissions..."

These groupings depend to a certain extend also on the system technologies applied in the aircraft being considered.

2.4 Certification

After one or several prototype aircraft are designed and manufactured they go through a series of *certification tests* in order to show compliance with the *certification requirements*. Compliance with the requirements may be shown by analysis, ground, or flight test – depending on the requirements or negotiations with the *aviation administration*. System test allocate a substantial part in the certification program. In Europe, certification of large aeroplanes is based on the Joint Aviation Requirements (**JAR-25**) or now: certification standards **CS-25** of the EASA, in the USA it is based on the Airworthiness Standards: Transport Category Airplanes (**FAR Part 25**). Large aeroplanes are basically those aircraft with a maximum takeoff mass of more than 5700 kg. JAR/CS and FAR are very similar, because the basic code for JAR-25/CS-25 is FAR Part 25 – further harmonization of the requirements is in progress. The certification of one or several prototype aircraft leads to a *type certificate* being issued. Aircraft in series production have to show *airworthiness* and *conformity with the prototype aircraft*. In service the aircraft have to be maintained according to an agreed maintenance schedule to prove continuous airworthiness.

JAR-25/CS-25 and FAR Part 25 are grouped into several Subparts:

Subpart F "Equipment" contains requirements for aircraft systems:

- § 1301 ... General
  § 1307: Miscellaneous Equipment (incl. Rain Protection)
  § 1309: safety requirements, loads, environmental conditions
- § 1302 ... Instruments and Navigation
  § 1329 and § 1335: Auto Flight
- § 1351 ... Electrical System
- § 1381 ... Lights
  also § 812: Emergency Lighting
- § 1411 ... Safety Equipment
  § 1416 ... : Ice Protection
- § 1431 ... Miscellaneous Equipment (incl. Cockpit Voice Recorder, Flight Recorder)
  § 1435 : Hydraulic Power
  § 1436 ... : Pneumatics
  § 1439 ... : Oxygen

Subpart E "Power Plant" also contains requirements for power plant related systems:

- § 951 ... Fuel System
- <u>§ 1195 ... Fire Protection (detection and extinguishing related to the power plant)</u>

Subpart D "Design and Construction" contains requirements for aircraft systems:

- § 651 ... Flight Control
- § 721 ... Landing Gear
- § 771 ... Equipment / Furnishings (personnel and cargo accommodations)

extended in "Safety Equipment" § 1411...
§ 799 : Water System

- § 831 ... Air Conditioning (ventilation, heating, pressurization)
- § 851 ... Fire Protection (detection and extinguishing related to the cabin)

Subpart J *Gas Turbine Auxiliary Power Unit Installation* contains requirements for airborne auxiliary power – i.e. the auxiliary power unit (APU). This subpart also includes further:

- § A1181 ... Fire Protection (detection and extinguishing related to the APU)

Interpretative material to most paragraphs is provided:

- FAR: Advisory Circulars (AC) (especially in **AC 25-17** and **AC 25-22**)
- JAR: Advisory Circular Joint (ACJ) (**ACJ-25**) and
  Advisory Material Joint (AMJ) (**AMJ-25**)

2.5 Safety and Reliability

On the one hand, the safety and reliability considerations of the aircraft systems are an integral part of the safety and reliability considerations of the whole aircraft. On the other hand, modern sophisticated aircraft depend very much on the proper functioning of their aircraft systems, so that safety and reliability considerations of aircraft systems have become of high importance in their own right. For this reason an aircraft systems specific approach to the topic is presented.

Safety is a state in which the risk is lower than a permissible risk. The risk is defined by the probability of a failure and the expected effect.

The *effect* of a failure describes the consequences of the failure (damage or injury).

The *probability of failure,* $F(t)$ is equal to the number of failures within a given period of time divided by the total number of parts in a test.

Table 2.2 Safety requirements for large aeroplane's systems ACJ No. 1 to 25.1309 (**ACJ-25**)

effect on aircraft and occupants	normal	nuisance	operating limitations emergency procedures	significant reduction in safety margins difficult for crew to cope with adverse conditions passenger injuries	large reduction in safety margins crew extended because of workload or environmental conditions serious injury or death of small number of occupants	multiple deaths, usually with loss of aircraft
category of effect	minor	minor	minor	major	hazardous	catastrophe
probability of a failure according to JAR 25 (per flight hour)	frequent 10^{0} ... 10^{-2}	frequent 10^{-2} ... 10^{-3}	reasonably probable 10^{-3} ... 10^{-5}	remote 10^{-5} ... 10^{-7}	extremely remote 10^{-7} ... 10^{-9}	extremely improbable $< 10^{-9}$

The *safety requirements* for aircraft systems are stated in § 1309 of the certification requirements **JAR-25/CS-25** and **FAR Part 25** and are listed here in Table 2.2. The probability of a failure in a system increases with the time period of operation and is specified for an operation time of one flight hour (FH). Obviously, the higher the effect of a failure is on aircraft operation, passengers, and the aircraft itself, the lower the permissible probability of such a failure has to be.

The *reliability* is the probability of survival $R(t)$. It is an item's ability to fulfill defined requirements for a specific period of time under specified conditions. A statement referring to the reliability of a system can only be made if the failure criteria are precisely defined.

The reliability or *probability of survival,* $R(t)$ can also be defined as the number of parts surviving within a given period of time divided by the total number of parts in a test.

$$R(t) + F(t) = 1$$

Although referring to the reliability $R(t)$, mostly the value of the probability of failure $F(t)$ is given (10^{-7}) because the reliability yields values more difficult to handle (0.9999999).

The *hazard rate function,* $z(t)$ is a measure of the probability that a component will fail in the next time interval, given that it has survived up to the beginning of that time interval. If the hazard rate function is constant (which is often assumed), it is called the *failure rate* λ. Failure rates of mechanical components are listed in **Rome 1985**, failure rates for electric and electronic equipment can be estimated using **MIL-HDBK-217**. The failure rate has units of 1 per flight hour (1/FH). The inverse of the failure rate is called the *mean time between failures* (MTBF) is often used in reliability and maintenance circles.

$$MTBF = 1/\lambda$$

The *failure to removal ratio* (FTRR) is a maintenance quantity. It shows the ratio of faults found in a component during a shop visit divided by the number of component removals. Unfortunately, the FTRR is especially low in case of electrical components (0.6 ... 0.7) and electronic components (0.3 ... 0.4). Hydraulic components (0.8 ... 0.9) and mechanical components (1.0) show better values. The product of MTBF and FTRR yields the maintenance cost driver, the *mean time between unscheduled removals* (MTBUR).

$$MTBUR = MTBF \cdot FTTR$$

The reliability and the probability of failure can be calculated from the failure rate

$$R(t) = e^{-\lambda t} \quad , \quad F(t) = 1 - e^{-\lambda t} \quad .$$

For low failure rates as they are common in aviation, the probability of failure calculated for a period of one hour ($F(t)$/FH) equals almost exactly the failure rate λ.

Systems are a combination of many components either in parallel, in series, or a combination of both. The reliability of a *series system* is equal to the product of is component values.

$$R_S(t) = R_1(t)\, R_2(t)\, R_3(t) \ldots$$

The failure rate of a series system is approximately the sum of the failure rates of its (reliable) components.

$$\lambda_S \approx \lambda_1 + \lambda_2 + \lambda_3 \ldots$$

The probability of failure of a *parallel system* is equal to the product of is component values.

$$F_P(t) = F_1(t)\, F_2(t)\, F_3(t) \ldots$$

The failure rate of a parallel system is approximately the product of is (reliable) component values.

$$\lambda_P \approx \lambda_1\, \lambda_2\, \lambda_3 \ldots$$

Systems can be depicted by *reliability block diagrams* (RBD). The analysis of large systems is carried out in successive stages. At each stage a small number of components connected either in parallel or in series is combined with equations as shown above. In this way the complexity of the system can be reduced step by step. The *fault tree analysis* (FTA) is an alternative method to deal with complex systems. Parallel system are combined by an OR gate symbol. Series systems are combined by an AND gate symbol. Top events are shown in a rectangle and basic failure causes are shown in circles. Software tools exist that support a FTA or the analysis of a RBD.

Systems might show cross-linkages so that some units are in more than one subsystem. One way of dealing with this problem is to use a theorem on conditional probability or to apply a truth table (**Davidson 1988**).

These approximate equations for series and parallel systems are quite useful in day-to-day business. The last equation also shows the ability of parallel systems to achieve low failure rates and thus high reliability. E.g. three components combined in parallel with a failure rate of 10^{-3} 1/FH each, yield an overall failure rate of 10^{-9} 1/FH. This is a failure rate that could not have achieved by a single component no matter how careful this component would have been manufactured and tested. This thought leads us to the concept of redundancy that is so typical in safety critical aircraft systems.

Redundancy is the existence of more means for accomplishing a given function than would simply be necessary. It is distinguished between

- homogeneous redundancy (the multiple means are identical) and
- inhomogeneous redundancy (the multiple means are of different type) also called: dissimilar redundancy or diversitary redundancy.

Safety critical aircraft systems often show *triplex* subsystems. The system architecture of safety critical computers may be even of *quadruplex* or *duo duplex* type.

The subsystems of a system with built in redundancy may all work together. If one subsystem fails, the others will just have to cope with a somewhat higher load. These systems are called *active-active* systems. Other systems may be of the *active-standby* type and need to perform a changeover in case of a failure. If the standby subsystem is constantly waiting for being activated, it is on *hot standby* otherwise on *cold standby*. The changeover should not be dependent on a changeover unit because this unit with its own limited reliability might fail and prevent the changeover. If an *active-standby* concept is applied, the subsystems should take turn in doing the job. This could be achieved with a planned changeover before every take-off. If the same subsystem stays in standby all the time, it might show an (undetected) *dormant failure* and hence would not be able to take up the job in case of failure of the first subsystem. Systems with a potential of dormant failures need regular maintenance checks and should be avoided.

An assumption has been made in the calculation of parallel systems that the failures of individual subsystems are independent of each other. That is that two or more subsystems do not fail simultaneously from precisely the same cause (except purely by chance). However, most systems have the potential of having more than one failure due to a common cause. These failures are called *common cause failures* (CCF). They tend to arise from errors made during design, manufacture, maintenance, operation, or environmental effects. For example, loss of power supply could cause both a running and a standby pump to fail (design error) or an empty fuel tank could cause all engines to quit (error in operation). Because these failure modes may appear to be outside the system being assessed, they can easily be overlooked, leading to too-optimistic assessments. Methods to avoid common cause failures in the design stage are the application of

- inhomogeneous redundancy (see above)
- segregation in the rooting of redundant wires, pipes, and ducts.
- separation of redundant components
- placing safety critical components in safe areas
- design of redundant components or software programs by independent teams with different (software) tools.

An aircraft should not only be safe to fly, it should also show very few errors that need the attention of maintenance personnel. In this respect we face a problem with high safety requirements. High safety requirements lead to the application of redundancy and hence more subsystems. The probability of a failure leading to the loss of the overall function can be reduced by redundancy, but the probability for the occurrence of any failure anywhere in the system is increased. Two subsystems with a failure rate of 10^{-3} 1/FH each yield an overall probability of failure of about 10^{-6} and a probability of any failure of $2 \cdot 10^{-3}$ (based on a one hour operation). Three subsystems yield an overall probability of failure of 10^{-9} and a probability of any failure of already $3 \cdot 10^{-3}$. The level of safety during flight can only be achieved if all subsystems work properly before take-off, but – as we have seen – the probability for any failure increases with an increased number of subsystems. These thoughts lead to what is called availability and dispatch reliability.

The *steady state availability* is defined as the probability that a system will be available when required, or as the proportion of total time that the system is available for use. Therefore, the availability of a system is a function of its failure rate λ and of its *repair rate* $\mu = 1/MTTR$, where MTTR is the *mean time to repair*

$$A_{SS} = \frac{MTBF}{MTBF + MTTR} = \frac{\mu}{\lambda + \mu} \quad .$$

The *instantaneous availability*, or probability that the system will be available at time *t* is

$$A_I = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{\lambda + \mu} e^{-(\lambda + \mu) t} \quad .$$

Often it is more revealing to consider system *unavailability* $U = 1 - A$. The instantaneous availability of an aircraft at the moment of dispatch from the gate is called *dispatch reliability*. Dispatch reliability for technical reasons primarily depends on the combined dispatch reliability of the aircraft systems. The airlines monitor their fleets dispatch reliability very carefully because high *dispatch unreliability* leads to delays and cancellations of flights and incurs delay and cancellation costs (see below). Dispatch reliability depends on the maturity of an aircraft program and is in the order of 0.99. A method to increase dispatch reliability is the introduction of *built-in test equipment* (BITE) into electronic systems. Though this adds complexity and might result in spurious failure indications, it can greatly reduce maintenance times by providing an instantaneous indication of failure location. Another method is to provide *extra redundancy* above the level required for safety reasons. This would than allow to dispatch with one subsystem inoperative. Components that are not needed for take-off may be known as *flying spares*. The pilot gets a clear indication about which subsystems or components need to be available at take-off from the *minimum equipment list* (MEL) written by the airline on the basis of the *master minimum equipment list* (MMEL) provided by the manufacturer and approved by the authorities.

The *reliability assurance* during the aircraft system design applies a couple of different methods. Some of them are listed here:

- Drawing a *fault tree* for a fault tree analysis (FTA) (see above) starts from consideration of system failure effects, referred to as top event. The analysis proceeds by determining how these can be caused by lower level failures. In this way it is a *top-down approach*.
- The *reliability apportionment* breaks an overall system reliability requirement down to individual subsystem reliabilities. This is common in large systems when different design teams of subcontractors are involved. Clearly it follows a *top-down approach*.
- In contrast, the *failure mode, effects, and criticality analysis* (FMECA) (**US MIL-STD-1629**) follows a *bottom-up approach*. It considers each mode of failure of every component of a system to ascertain the effects on system operation and defines a *failure mode criticality number*.
- The *zonal safety analysis* (ZSA) looks at an aircraft not from a functional point of view, but rather looks at the components location. The ZSA checks installation rules, checks the effects of events originating within the zone, in other zones, or on the outside.

Software defies the above calculations and methods. However information can be drawn from **RTCA/DO-178B** that deals with *software considerations* in airborne systems and equipment. *Environmental conditions* for airborne equipment are presented in **RTCA/DO-160D**.

2.6 Mass

Mass estimation of aircraft systems is part of the mass (or weight) estimation of the whole aircraft. The mass of all the aircraft systems m_{SYS} amounts to 23% ... 40% of the aircraft's empty mass m_{OE}, where m_{OE} is the mass related to the Operational Empty Weight, OEW. The figure 23% is true in case of a modern long-range airliner, whereas 40% is about right for a smaller aircraft like a business jet. Hence for civil jet transport we may write

$$\frac{m_{SYS}}{m_{OE}} \approx 0.23 \ldots 0.4 \quad .$$

On average this ratio comes to 1/3 and that is what has been stated above. Taking into account the ratio of the aircraft empty mass m_{OE} and the maximum takeoff mass m_{MTO} (m_{MTO} is the mass related to the Maximum Takeoff Weight, MTOW)

$$\frac{m_{SYS}}{m_{MTO}} \approx 0.11 \ldots 0.23 \quad .$$

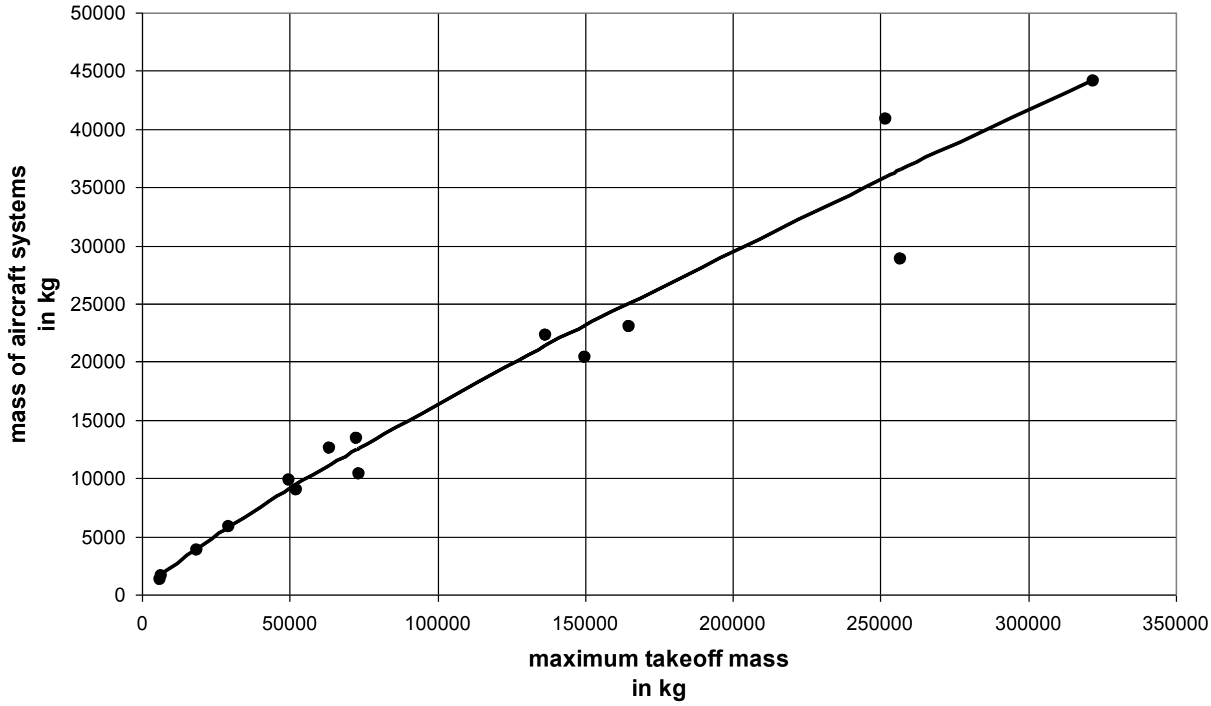


Figure 2.1 Mass of aircraft systems of selected civil jet aircraft plotted against their maximum takeoff mass

Figure 2.1 shows the mass of aircraft systems of selected civil jet aircraft as a function of their maximum takeoff mass. We follow a *top down approach* and fit a curve to this data to obtain

$$m_{SYS} = 0.92\, m_{MTO}{}^{0.85} \qquad \text{for } m_{SYS} \text{ and } m_{MTO} \text{ in kg} .$$

This function is shown in Figure 2.1. The average relative mass of the individual systems of civil jet aircraft is given in Table 2.3.

Table 2.3 Average relative mass of aircraft systems of civil jets

identifier	name of system	average relative mass of system
21	air conditioning	6%
22	auto flight	1%
23	communications	2%
24	electrical power	10%
25	equipment / furnishings	24%
26	fire protection	1%
27	flight controls	8%
28	fuel	3%
29	hydraulic power	7%
30	ice & rain protection	< 1%
31	indicating / recording systems	< 1%
32	landing gear	27%
33	lights	2%
34	navigation	3%
35	oxygen	1%
36	pneumatic	2%
38	water / waste	1%
49	airborne auxiliary power	2%

Some aircraft systems, like the landing gear system (ATA 32) and the equipment and furnishings (ATA 25) account for a large percentage of the total aircraft system mass. The avionic system relative mass is 6% on average, but this figure depends on aircraft size, because the amount of avionics needed in jet aircraft tends to be nearly constant. For this reason, the relative mass of avionic systems of business aircraft may be as high as 14% and may be as low as 5% in case of a large civil transport. As can be seen in Table 2.3, a number of systems are of minor importance for aircraft system mass predictions. This is also true for the fire protection system.

A *bottom up approach* follows statistical techniques. It uses system parameters to predict the mass of the system. Equations are given in **Raymer 1992**, **Roskam 1989**, or **Torenbeek 1988**. In addition, the knowledge gathered in papers from the Society of Allied Weight Engineers should be taped. See **SAWE 2002**.

Statistics of aircraft system mass have to take as many aircraft into account as possible in order to broaden the statistical base. This however is really possible only, if mass data is based on comparable and detailed mass breakdowns. Unfortunately, there are many quite different breakdowns in use and it is found that system boundaries overlap from one method to another or are not well defined in the first place. So in the present situation, it is very difficult to use and compare mass data and mass equations based on one of these breakdowns in another setting. This situation adds to the difficulties that exist with statistical methods anyhow and explains why *statistical mass equations for systems or subsystems do not provide particularly reliable data*.

Boeing has used a breakdown format called *Weight Research Data 1* (WRD1). In the literature breakdowns very similar to WRD1 can be found. Airbus uses so called *Weight Chapters*. Another approach is given with **MIL-STD-1374**. Above we have used a mass breakdown according to the *ATA 100 Chapter numbering*. **ATA 100** also includes a widely accepted *mass breakdown for weight and balance manuals*. This breakdown, however, provides only as much detail as needed in aircraft operation but not enough detail for aircraft system design. Detailed system mass predictions are also necessary for *Center of Gravity* (CG) calculation for the aircraft.

Practical mass predictions will look like this: In the early design stage, statistical methods are used. The aircraft manufacturer can also use the information contained in the mass database of older aircraft for the new design. In a later design stage a subcontractor will offer a system or an item of equipment. The subcontractor has probably quite a good idea what the item's mass will be from a comparison with similar items already built. If the required size of equipment is different from an older one, a mass estimate may be obtained from scaling. In the final development stage, mass accounting can be based on the actual mass of components that are already delivered to the manufacturer.

There is another virtue in mass predictions: The *system mass* has been *used for* rough *cost calculations*. This is possible when from statistics costs per unit mass are known and costs are assumed to be proportional with mass. Evidently, the concept of calculating costs from mass fails, if expensive mass reduction programs are being applied. The concept also fails, if highly sophisticated technologies are applied to reduce mass that are not considered in the established cost per unit mass.

2.7 Power

Gliders use the energy of up-currents, solar powered vehicles use the energy from the sun. Also human powered flight has been demonstrated. Propulsive power for any other "down to earth" flying depends on fuel. This fuel is used in the aircraft main engines. *Secondary power* systems (hydraulic power, electrical power, pneumatic power) in turn draw on engine power to supply their client systems with *non-propulsive power* in all those cases where functions are not directly actuated by the pilot's muscles. This is the simple picture of the aircraft power management. However, there is more to it, due to safety requirements and the need for autonomous operation of the aircraft on the ground with engines shut down.

Various *secondary power sources* are available in the air and on the ground. *Secondary power loads* may be grouped into two major categories. *Power conversion* transforms secondary power from one form into another.

An **auxiliary power unit** (APU) is used to produce power from fuel independent of the main engines. An APU is a gas turbine engine. Most often it produces electrical power and pneumatic power. A **ram air turbine** (RAT) is used to produce hydraulic or electrical power from the kinetic energy of the air passing by the aircraft. This is possible even without fuel and without the main engines running – at least as long as the aircraft soars down consuming its potential energy. Except from the pilot's own energy, the **aircraft batteries** are the last and very limited source of energy on board.

Ground power may be available on the apron or in the hangar. The aircraft may directly be supplied with electricity, high-pressure hydraulic fluid, pressurized air, and/or air conditioned air. Human power could work a hand pump in the hydraulic system. If only electrical ground power is available, the aircraft depends on its secondary *power conversion* capabilities to activate also the hydraulic and pneumatic system. Without ground equipment and with engines shut down, the aircraft may operate autonomously if it is equipped with an auxiliary power unit (APU).

First of all, **secondary power loads** may be grouped into

- *technical loads* consumed by equipment required to operate the aircraft safely
- *commercial loads* consumed by equipment required to increase passenger comfort and satisfaction, and the airlines needs to provide these services.

Power conversion among different secondary power systems is used to increase overall system reliability. If we consider electrical power, hydraulic power, and pneumatics:

- *Six different unidirectional conversions* are possible. Examples are:
  - electrical to hydraulic power conversion: electric motor driven pump
  - pneumatic to hydraulic power conversion: air turbine motor driven pump
  - hydraulic to electrical power conversion: hydraulic motor driven generator.
- *Three different bidirectional conversions* are possibilities that allow a two way power conversion among two different secondary power systems within one conversion unit.

For many years, hydraulic, pneumatic and electrical power supply in commercial aircraft had been sufficient to meet the demands from technical and commercial loads. System design had laid an emphasis on reliable, lightweight solutions. From fuel input to system output, *very low overall efficiencies* had been accepted in exchange.

In recent years it has been observed that aircraft face *increasing technical loads*. Also market trends together with increasing flight durations have resulted in *higher commercial loads* caused for example by today's standards in inflight entertainment. Possibilities for power off-takes do not increase proportional with aircraft size. Large modern civil aircraft are therefore likely to face limitations of cost effectiveness, geometry, or weight with present day technologies in an attempt to meet these new power load levels. The aerospace industry has identified a potential *deadlock*, where power needs will exceed the maximum available power supply.

In the future, a move towards electrical power as a single source to meet secondary power demands is expected to be a solution to the problem. The last aircraft generation has brought *steering by wire*. The next generation of aircraft might bring *power by wire*.

2.8 Costs and Trade-Off Studies

Trade-off studies play an important roll in the aircraft system design. *Trade-off studies* try to find the best among several system design proposals. *Safety* aspects allow no compromise because certification regulations have to be closely followed. Also *performance* aspects do not leave much room, for the reason that usually only as much performance as necessary to do the job will be allowed for. More powerful aircraft systems will unnecessarily produce *costs* – costs that add to the overall costs of the aircraft. Clearly, costs need to be reduced as much as possible to come up with a viable product. Therefore, it is the costs aspect that mostly decides in trade-off studies which system design will get on board the aircraft.

At the <u>aircraft system level</u>, evaluations are done in the early design stage by looking separately at <u>various aspects</u>:

- mass
- maintainability
- reliability
- system price
- other specific criteria depending on the aircraft system in question.

Based on these separate evaluations, the simplest way to come up with one single figure of merit for a proposal is to subjectively define a *weighted sum* of the results *based on* the *individual criteria*.

In contrast to the above approach, at the <u>aircraft level</u> an evaluation is traditionally based primarily on <u>one single figure</u>: the Direct Operating Costs, DOC. Also DOC take account of criteria like mass, maintainability, and aircraft price, but DOC combine these separate parameters unambiguously by calculating their economical implications. Subjective manipulations of the results are largely avoided in this way.

Unfortunately, aircraft DOC-methods cannot be taken "as is" to apply this advantage to an aircraft system evaluation. In contrast to aircraft DOC methods, a DOC method on the systems level must incorporate many system-specific parameters. Therefore, a *DOC method for aircraft systems* called DOC_{SYS} has been developed (**Scholz 1998**) which follows the principles of aircraft DOC methods as closely as possible, while taking aircraft system peculiarities into account as much as necessary.

$$C_{DOC,SYS} = C_{DEP} + C_F + C_M + C_{DEL} + C_{SH}$$

C_{DEP}	<u>dep</u>reciation of the system (a function of system price)
C_F	<u>f</u>uel costs caused by the system
C_M	direct <u>m</u>aintenance costs caused by the system

C_{DEL} delay and cancellation costs caused by the system

C_{SH} capital costs caused by necessary system spare parts on stock (spare holding)

The fuel costs C_F are due to:

- transportation of the systems mass (being fixed or variable during flight)
  (taking into account the lift-to-drag ratio of the aircraft and the specific fuel consumption of the engines)
- power off-takes from the engines
  (by electrical generators or hydraulic pumps)
- bleed air off-takes
  (for the pneumatic system)
- ram air off-takes
  (e.g. for the air conditioning system)
- additional drag caused by the presents of aircraft systems, subsystems, or single parts (e.g. due to drain masts).

In contrast to **Scholz 1998** who combines various system aspects to US$, **Shustrov 1999** combines system mass effects and effects related to the system's energy consumption to a quantity called *starting mass*.

Proprietary methods for the evaluation of aircraft systems are in use at aircraft manufacturers and subcontractors.

2.9 Documentation of Aircraft Systems

Documentation requirements are laid down in ATA iSpec 2200 (**ATA 2200**). **Scholz 2002** gives an introduction to standards related to aircraft documentation with an emphasis on the ATA iSpec 2200.

3 Aircraft Fire Protection Fundamentals

3.1 Definition

Those fixed and portable units and components which detect and indicate fire or smoke and store and distribute fire extinguishing agent to all protected areas of the aircraft; including bottles, valves, tubing, etc. (**ATA 100**)

3.2 Detection Fundamentals

Fire detection comprises that part of the fire protection system, which is used to sense and indicate the presence of overheat, smoke, or fire (**ATA 100**).

There are various **ways in detecting a fire**, including:

- **direct observation** by cockpit & cabin crew (optical indication, sensing of heat or smell)
- **overheat detector**
- **smoke detector**
- rate-of-temperature-rise detector
- inspection by video camera
- fiber-optic detectors
- thermal imaging devices
- radiation sensing devices
- ultraviolet aircraft fire detection system
- detection of combustion gases like CO or CO_2

Designated **fire zones** must be equipped with fire detection and extinguishing equipment. Designated fire zones are (**JAR-25/CS-25**, **FAR Part 25**):

- power plant compartment (§ 1181)
- auxiliary power unit (APU) compartment (§ A1181)
- combustion heater chamber (§ 859)

Fire detection and extinguishing equipment is required for cargo compartments according to the **cargo compartment classification** (§ 857, **JAR-25/CS-25**, **FAR Part 25**):

- *Class A* compartments are accessible in flight. A fire in the compartment would be easily discovered by a crewmember while at his station.
- *Class B* compartments provide access in flight to enable a crewmember to use a hand fire extinguisher. The compartments are equipped with a smoke or fire detector.
- *Class C* compartments are equipped with a smoke or fire detector and a built-in fire extinguishing system.

- *Class D* compartments are able to completely confine a fire without endangering the safety of the aircraft.

Lavatories must be equipped with a smoke detector system, and lavatories must be equipped with a built-in fire extinguisher for each disposal receptacle for towels, paper, or waste, located within the lavatory (§ 854, **JAR-25/CS-25**, **FAR Part 25**).

Other areas equipped with fire detectors may be the avionic compartment or the landing gear bay.

```
fire detector
├──>overheat detector
│     ├──>point detector
│     │     ├──>thermal switch
│     │     │     ├─>spot detector
│     │     │     └─>bimetallic thermostat
│     │     └───>thermocouple
│     └──>continuous-loop detector
│           ├──>electric
│           │     ├─>averaging
│           │     └─>discrete
│           └──>pneumatic
├──>smoke detector
│     ├──>ionization type
│     └──>photoelectric type
└──>...
```

Figure 3.1 Roadmap to the most widely used detection devices

Fire detectors are generally either *overheat detectors* or *smoke detectors*. From the beginnings until today, these and other **fire detection devices** for aircraft have evolved from only a few US companies: *Walter Kidde*, *Fenwal*, and *Systron-Donner*. Their component designs will be presented here (**Hillman 2001**). The roadmap to the following discussion of the most widely used detection devices is presented in Figure 3.1.

3.3 Overheat Detection

In the 1940's overheat detection coverage in the engine nacelle was done with *thermal switches* or *thermocouples*. Several of these switches were positioned in parallel at different places around the engine. A fire alarm was activated, if one of the switches was triggered. However, it was recognized that these **point detectors** were very limited with regard to area of coverage. So, the placement of the point detector became the most critical factor of how successful the detection system would be.

In the early and mid 1950's **continuous-loop detectors** were introduced to the aircraft industry. This technology became the most popular detection approach for aircraft engines and has remained so to this day. There are *electric* continuous-loop detectors and *pneumatic* continuous-loop detectors. The electric continuous-loop detectors are of either *averaging type* or *discrete type* (Figure 3.2).

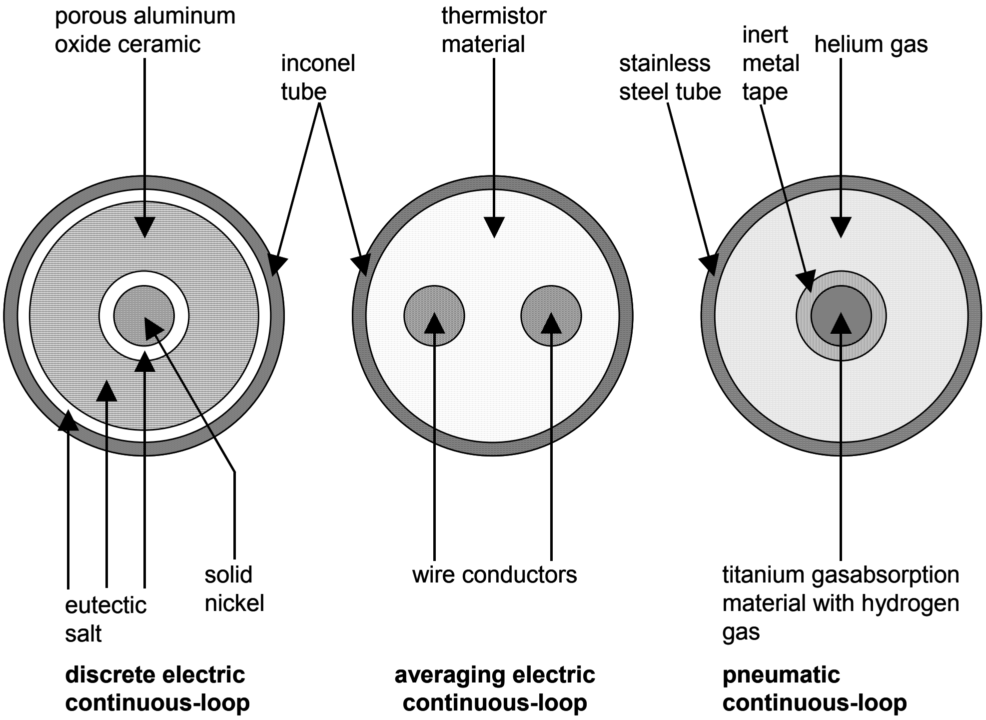


Figure 3.2 Cross section of continuous-loop detectors

Some versions of the electric continuous-loop detectors are dependent on the amount of element heated to reach their alarm threshold level and have been termed **averaging electrical continuous-loop detectors**. Their alarm threshold averages the temperature over its entire length. These detectors monitor either changing electrical *resistance* alone, or *resistance and capacitance* in conjunction with each other The electrical based continuous sensing elements have one or two internal wire conductors embedded in a ceramic-like thermistor material that are contained in a metallic outer tube. As the surrounding temperature increases, the resistance between the inner conductor and the outer tube conductor decreases, while the capacitance increases. When two internal wire conductors are embedded in the sensing element, the resistance change between these two wires is typically measured. When the resistance between the internal conductor and the external sensing element tube drops to some pre-determined level (and/or the capacitance increases), which corresponds to the desired alarm temperature, a monitoring *control unit* issues a hazard signal. When the hazard condition is eliminated and the temperature returns to normal, the resistance increases and the capacitance decreases, thereby canceling the alarm. Multiple trip resistance / capacitance settings can be used when multiple thresholds are pursued to indicate fire versus overheat.

Shortly after the first averaging type detection systems, also **discrete electrical continuous-loop detectors** were introduced (Figure 3.3). The discrete system utilizes sensing elements that are essentially independent of the length of element heated to achieve its alarm threshold. These systems employ a sensing element which, like the electrical based averaging systems, have either one or two internal wire conductors embedded in a ceramic-like core material, surrounded by a metallic outer tube. The ceramic core is impregnated with eutectic salt. The salt melts at its eutectic melt temperature, even when only a very short length of element is heated. When this occurs, the electrical resistance between the inner conductor and the outer tube very rapidly breaks down (also the capacitance increases), and a monitoring control unit signals a fire or overheat, whichever is appropriate for the intended application. The characteristics of the discrete type are paramount for reliable, early warning of small, discrete overheat events, such as bleed air duct failures. By its nature, the discrete type cannot provide multiple alarm thresholds or any kind of analog temperature trend information.

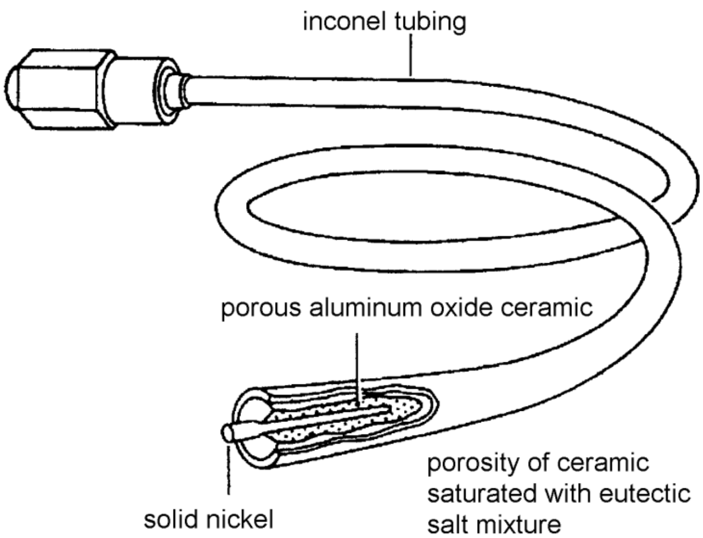


Figure 3.3 Discrete electric continuous-loop detector. Pneumatic system, leak detection (AMM A321 ATA 36)

Pneumatic based **continuous-loop detectors** rely on increasing gas pressure to achieve the alarm threshold. These sensing elements have a hydrogen charged core surrounded by helium gas, contained in a metallic outer tube. As the surrounding temperature increases, the helium gas pressure increases, closing a pressure switch, thereby issuing an alarm. As the temperature returns to normal, the pressure decreases and the alarm is canceled. If a localized, high temperature event is present, the hydrogen core also out-gasses its hydrogen gas, increasing the internal pressure and closing the pressure switch. As the sensing element cools, the hydrogen absorbs back into the core so that the internal pressure decreases, removing the alarm output. A leak in the detector can be discovered with an integrity switch opening due to a loss of pressure. (Figure 3.4)

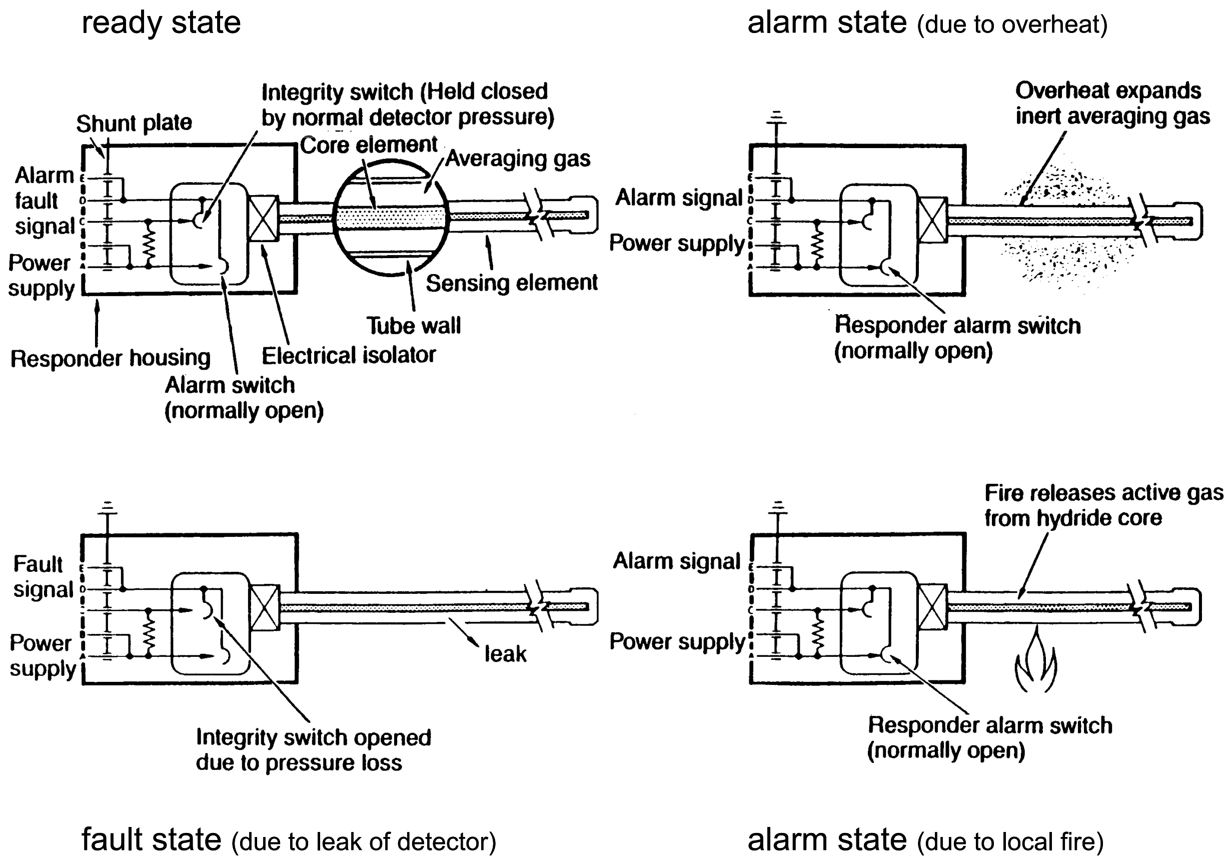


Figure 3.4 Principle of pneumatic continuous-loop detector (GEN FAM A321 ATA 26)

Overheat detection may be applied in areas of the *engine*, *auxiliary power unit* (APU), *bleed air ducts*, and in the *landing gear bay*.

3.4 Smoke Detection

Smoke detection systems are the primary means of fire detection used in cargo compartments. This has not changed much over the last 50 years. While solid state electronics and new optics and new processing algorithms have been introduced, the basic mechanism that these detectors operate under has remained the same. There are two basic designs of smoke detectors: *ionization* and *photoelectric*.

Ionization type smoke detectors monitor ionized combustion by-products as they pass through a charged electrical field. Photoelectric detectors measure light attenuation, reflection, refraction, and/or absorption of certain wavebands. Ionization smoke detectors were used from the early years. The typical approach was to use a radioactive isotope as the source to charge the combustion products (Figure 3.5). However, this source may also charge everything else, including dust and fine water droplets and can make ionization type detectors unreliable. Ionization type smoke detectors have been used, primarily by the commercial aviation community, in lavatories and cargo compartments.

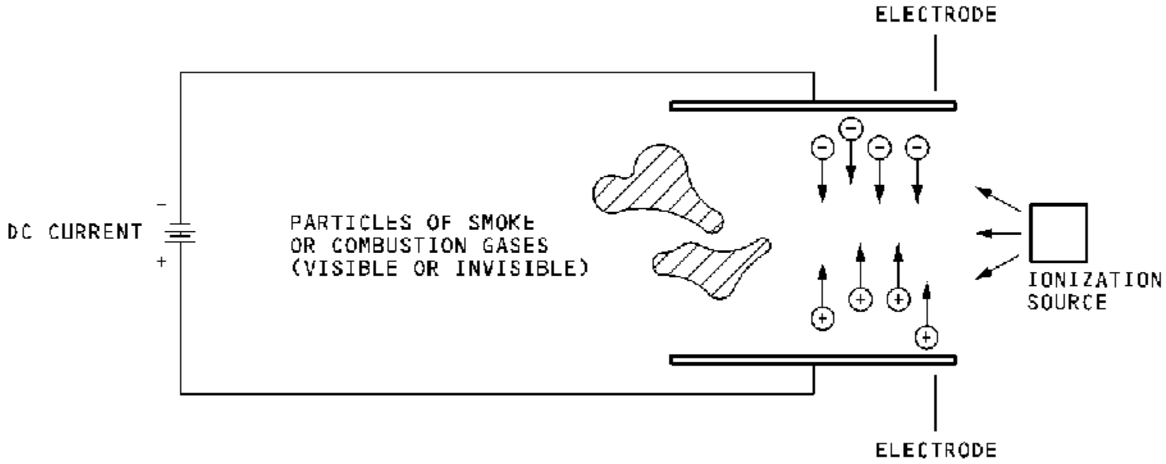


Figure 3.5 Principle of ionization type smoke detector (GEN FAM A321 ATA 26)

Photoelectric type smoke detectors have become the industry standard for smoke detectors. This is not to imply that photoelectric based detectors were overly impressive with respect to freedom from false alarms. These types of detectors, too, have been quite troublesome over the years. Most cargo compartment applications use aerospace quality photoelectric type smoke detectors that rely on scattered or reflected light radiation caused by a particulate matter between a radiation emitting source and a detector device. Solid-state photoelectric smoke detectors use a long-life light emitting diode (LED) as its source of light.

There are still many limitations associated with smoke detector applications. Their operational success depends highly on the placement of these devices with respect to where a fire event is. But there are also **problems with other detectors**. Since one cannot count on a visual line-of-sight of a cargo bay fire, future cargo detection technologies cannot rely on the use of video camera or thermal imaging devices. Deep seated fires and/or fires inside LD3 containers will still be hidden. This makes also stand-alone thermal based systems impractical. While combustion gases, such as CO or CO_2, could be monitored, these gases could have been introduced from sources other than fires.

Smoke detection may be applied in the *cargo compartment*, *lavatories*, *galleys*, and *avionic compartments*.

3.5 Extinguishing Fundamentals

Fire extinguishing comprises that part of the fire protection system with those fixed of portable systems used to extinguish a fire (**ATA 100**).

A **fire classification** includes three types of fire relevant to aircraft application:

- *Class A*:
  Fires involving ordinary combustible solid materials, such as wood, paper, rubber and many plastics
- *Class B*:
  Fire involving flammable liquids, oils, greases, paints, lacquers and flammable gases
- *Class C*:
  Fires involving energized electrical equipment.

Each of these types of fires requires its own suitable **type of extinguisher**:

- *Water* extinguishers are used on Class A fires only. Water must never be used on Class C fires and can be counter-productive on Class B fires.
- *CO_2* extinguishers are specifically used to combat Class C fires. A hand-held CO_2 extinguisher includes a megaphone-shaped nozzle that permits discharge of the CO_2 close to the fire. Be aware that excessive use of CO_2 extinguishers robs a closed area of oxygen. In an aircraft, this could affect passengers.
- *Dry chemical* fire extinguishers can be used on Class A, B, and C fires. Use of this extinguisher on the flight deck could lead to temporary severe visibility restrictions. In addition, because the agent is nonconductive, it is possible that it might interfere with electrical contacts of surrounding equipment.
- *Halon* has almost exclusively been in use in portable aircraft fire extinguishers.

In the *late 1940's* time frame, the very effective halogenated hydrocarbon (later termed *halon*) fire extinguishing agents were introduced. The primary agents used for fixed fire extinguishing systems were methylbromide (Halon 1001) and bromochloromethane (Halon 1011). **Halon 1011** agent eventually displaced Halon 1001 for engine extinguishing systems primarily because of lower toxicity and corrosion.

The halons that were introduced in the *early 1950's* were less toxic than Halon 1011. Over the next 30 years, the higher vapor pressure bromotrifluoromethane (Halon 1301) essentially displaced most of the Halon 1011. Because of the high vapor pressure of **Halon 1301**, the use of elaborate spray nozzles and spray bars was no longer required. The new Halon 1301 extinguisher systems were designed to discharge at a very high rate. This concept was called the *high rate discharge* (HRD) concept. The high rate discharge systems utilized halon that was pressurized to 600 psig (40 bar).

Hand-held dibromoflouromethane (**Halon 1211**) and/or water extinguishers have been the approved approach for accessible fire fighting.

In *recent years*, due to international agreement to ban the production and use of ozone depleting substances, including all the halons, the need for **alternate extinguishing agents** to the halons has arisen. However, the use of halons is still permitted for essential applications, such as aircraft, until a "suitable" replacement agent can be developed, approved, and certified for aircraft use. Until that time comes, existing stocks of halon, recovered from decommissioned fire protection systems, are sufficient to support many years of aircraft production and use. Upon review of alternative agents, it is evident that there is no clear winner with respect to a replacement for Halon 1301 in fire suppression systems that will use similar hardware and architecture. Each candidate has at least one characteristic that makes it inferior to Halon 1301.

3.6 Engine and APU Extinguishing

First step: **the engine is shut down** and combustible fluid entry (jet fuel, hydraulic fluid, and engine oil) into the engine compartment is stopped. This is necessary in order for the engine extinguisher to be effective. If the engine were not shut off, the fire would probably just relight after the extinguishing agent dissipated. Because of this practice, only multi-engine aircraft utilize extinguishing systems.

Second step: **the extinguishing agent flows from a pressure vessel** through rigid pipes and is sprayed in the engine-protected zones.

Third step: If after some time (30 s) the fire warning still remains on, **extinguishing agent from a second pressure vessel** (if still available for that engine) **may be used** for further fire extinguishing.

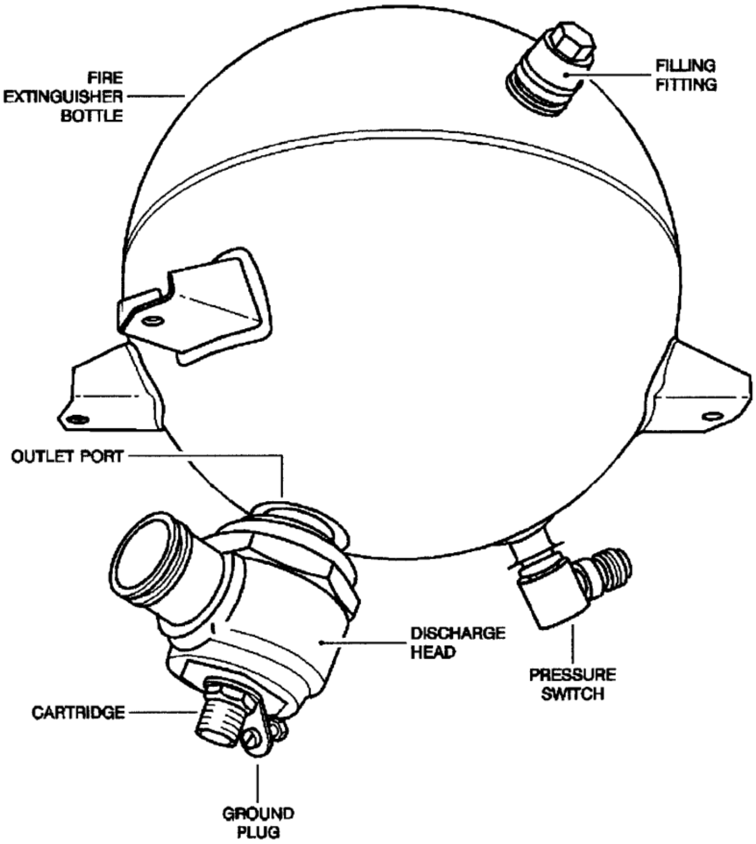


Figure 3.6 Fire extinguishing bottle (GEN FAM A321 ATA 26)

The extinguishing agent is stored in high-pressure vessels commonly called *bottles*. A **spherical shaped pressure vessel** design represents the most weight and volume efficient geometrical configuration for containing the most amount of agent. In addition, it is also the optimum shape with respect to stress levels in the vessel's material. The spherical pressure vessel is the most popular design (Figure 3.6). Other details of the design are stated in § 1199 of **JAR-25** and **FAR Part 25**.

APU fire extinguishing is technically similar to engine fire extinguishing, however, the APU may only be equipped with one bottle.

3.7 Cargo Extinguishing and Inerting

Cargo compartments have traditionally been protected with hand-held fire extinguishers if the compartment was accessible and with a fixed Halon 1301 fire extinguishing/inerting system if the compartment was not accessible.

Like engine extinguishing systems, a cargo compartment suppression system is required to provide an initial peak volumetric agent concentration to "knock-down" the fire. Since complete fire extinction cannot be assured, a cargo suppression system is required to maintain a lower concentration for some extended period of time. The compartment is thus inerted to prevent the fire from re-igniting or growing. The typical time period for keeping the compartment inert against flaming combustion is 60 minutes. In case of *extended range twin-engine operations* (ETOPS) inerting periods are much higher.

A typical cargo fire suppression system will consist of two fire extinguishers connected to single or multiple cargo compartments by distribution plumbing. The “knock-down” or *high rate discharge* (HRD) extinguisher provides the initial high volumetric concentration and the second *low rate discharge* (LRD) extinguisher provides the metered lower inerting concentration.

3.8 Passenger Compartment Extinguishing

Fires that could occur in an aircraft cockpit or cabin are Class A, B, and C. The number of hand-held fire extinguishers to be carried in an aircraft is determined by § 851 of the certification regulations (**JAR-25/CS-25**, **FAR Part 25**).

For aeroplanes with a passenger capacity of 20 or more, each lavatory must be equipped with a built-in fire extinguisher for each disposal receptacle for towels, paper, or waste, located within the lavatory. The extinguisher must be designed to discharge automatically into each disposal receptacle upon occurrence of a fire in that receptacle (§ 854 **JAR-25/CS-25**, **FAR Part 25**).

4 A321 Fire Protection

4.1 Fire Protection General

The Aircraft fire protection system comprises:

- fire and overheat detection and extinguishing system for
  - the engines,
  - the Auxiliary Power Unit (APU),
- smoke detection and extinguishing for
  - the cargo compartment (optional system),
  - the lavatories,
- smoke detection for
  - the avionic bay,
- portable fire extinguishers for
  - the flight compartment,
  - the passenger cabin.

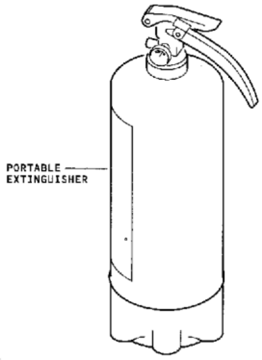


Figure 4.1
Portable fire extinguisher

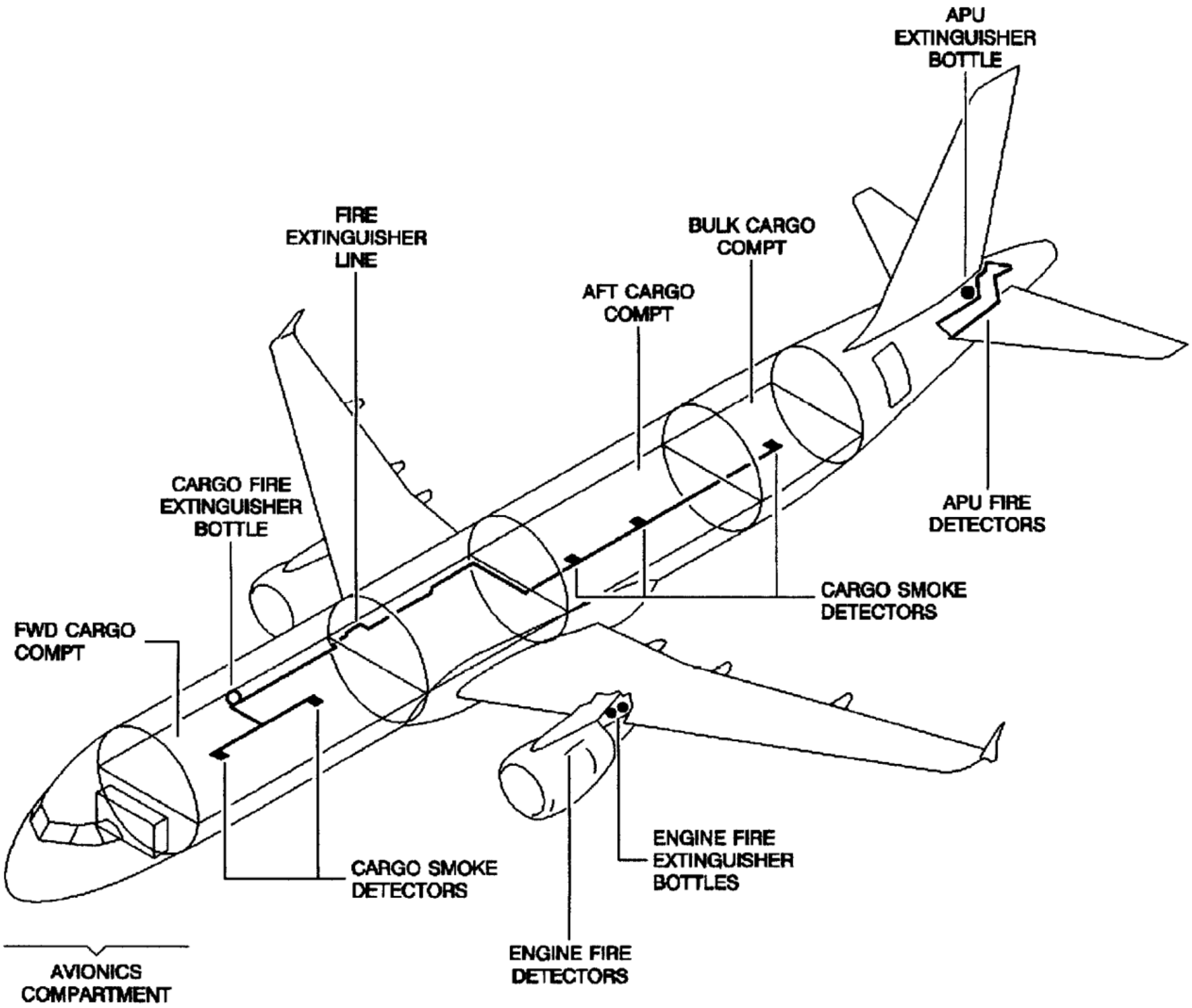


Figure 4.2 The fire protection system: component locations (AMM A321 ATA 26-00)

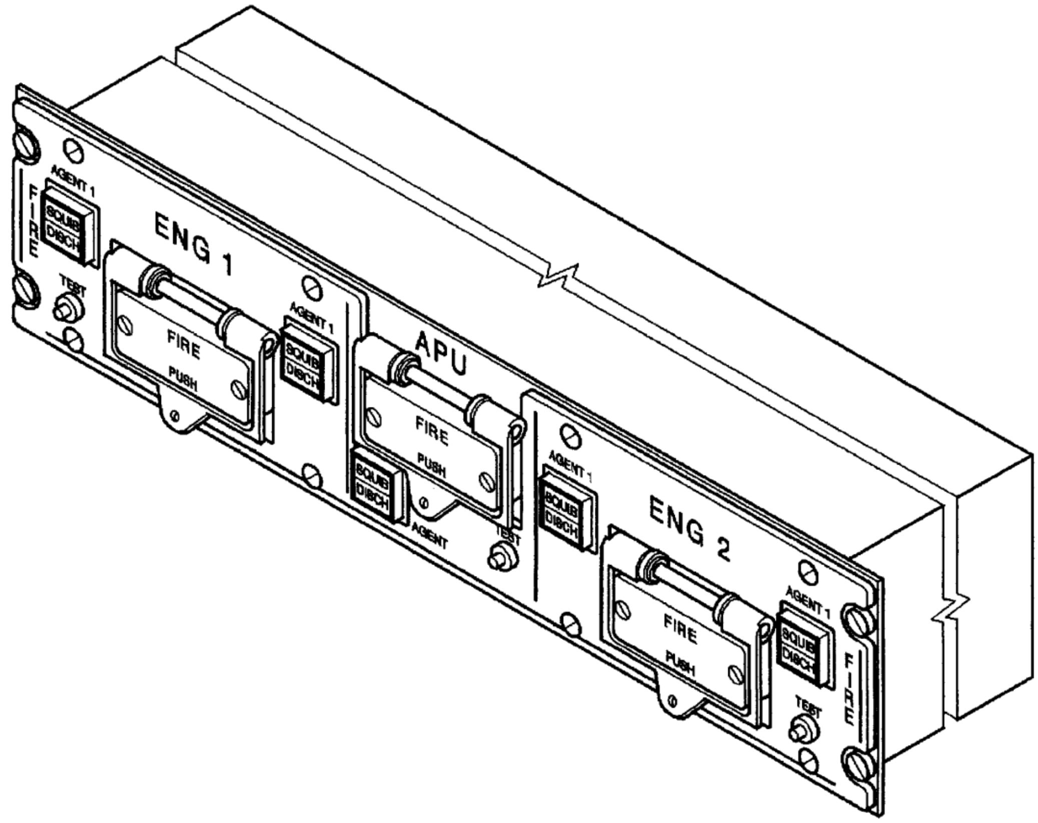


Figure 4.3 Engine and APU fire overhead panel (AMM A321 ATA 26-12)

4.2 Engine Fire Detection and Extinguishing

Fire Detection System

General: A fire can be due to excessive overheat or flammable fluid leaks and can endanger the aircraft safety. For this reason, thermo-sensitive elements are installed that can detect both: a fire *and* an overheat conditions. The fire detection system is of the electro-pneumatic type.

The engine fire detection system comprises for each engine:

- on the ENG/APU FIRE panel:
  - one ENG 1(2) FIRE push button switch,
  - one TEST push button switch,
- a Fire Detection Unit (FDU),
- two fire detection loops with three fire and overheat detectors.

Principle: On each engine, there are two continuous **fire detection loops** for fire and overheat detection. The loops are connected to a **Fire Detection Unit (FDU)** which monitors the fire detection loops. The connection is made through an AND logic. This means that both loops have to report a fire before a fire warning is issued. In this way, spurious fire warnings are avoided. In case of failure of one loop, the AND logic becomes an OR logic. This means that a reported fire situation of one remaining loop is now enough to issue a fire warning. The aircraft can be released for flight in this configuration. The FDU indicates the loss of a fire detection loop to the crew members through the Flight Warning System (FWS).

The **Fire Detection Unit (FDU)** processes for each engine the signals received from the two fire detection loops in channel *A* respectively channel *B*.

A **fire detection loop** on an engine

- comprises **three fire and overheat detectors** connected in parallel which are installed in different fire zones in the nacelle and pylon,
- is connected to either channel *A* or channel *B* of the FDU,
- is connected through the related channel, to the lamps in a red warning light in the ENG 1 respectively ENG 2 FIRE push button switch located on the ENG/APU FIRE panel on the overhead panel.

Each **fire and overheat detector** has a sensing element and responder assembly.

A **sensing element** is a tube 1.6 mm in outer diameter and 0.46 mm in thickness. It contains a hydrogen-charged titanium core with a spiral wound around it. This spiral is made of a material which has a special property: 1.) it can generate a hydrogen gas when exposed to high temperatures 2.) it can absorb the gas when cooled. The gap between the sensing-element outer-tube wall and the core is filled with helium, an inert gas that does not take part in the process of generating and absorbing the hydrogen. The initial pressure of the helium is related to the pre-set temperature threshold selected for each sensing element. The sensing element reacts according to the ideal gas law. This means that the gas pressure increases *a)* as the temperature in the sensing element increases (overheat detection) or *b)* as gas is generated by the spiral (fire detection). One end of the sensing element is hermetically soldered and the other one is connected to a 25.4 mm diameter body called responder.

The **responder** experiences the gas pressure from the sensing element. It contains a chamber connected to two pressure switches: an ALARM switch and a MONITOR switch. The free end of the responder is connected to the aircraft electrical circuit. The detector has two sensing functions. It responds *a)* to an overall "average" temperature increase above a defined threshold or *b)* to a highly localized "discrete" temperature caused by impinging flame or hot gases. (Note: "*a)*" and "*b)*" correspond to the physical phenomena explained above.) This results in the ALARM switch closure. The "average" and "discrete" temperatures cannot be adjusted. The "average" and "discrete" functions are reversible. When the sensor tube has cooled, the average gas pressure decreases and the core material absorbs the hydrogen gas. If the detector leaks, the gas pressure decrease causes the MONITOR switch to open and generates a detector fault signal. The system then does not operate during test.

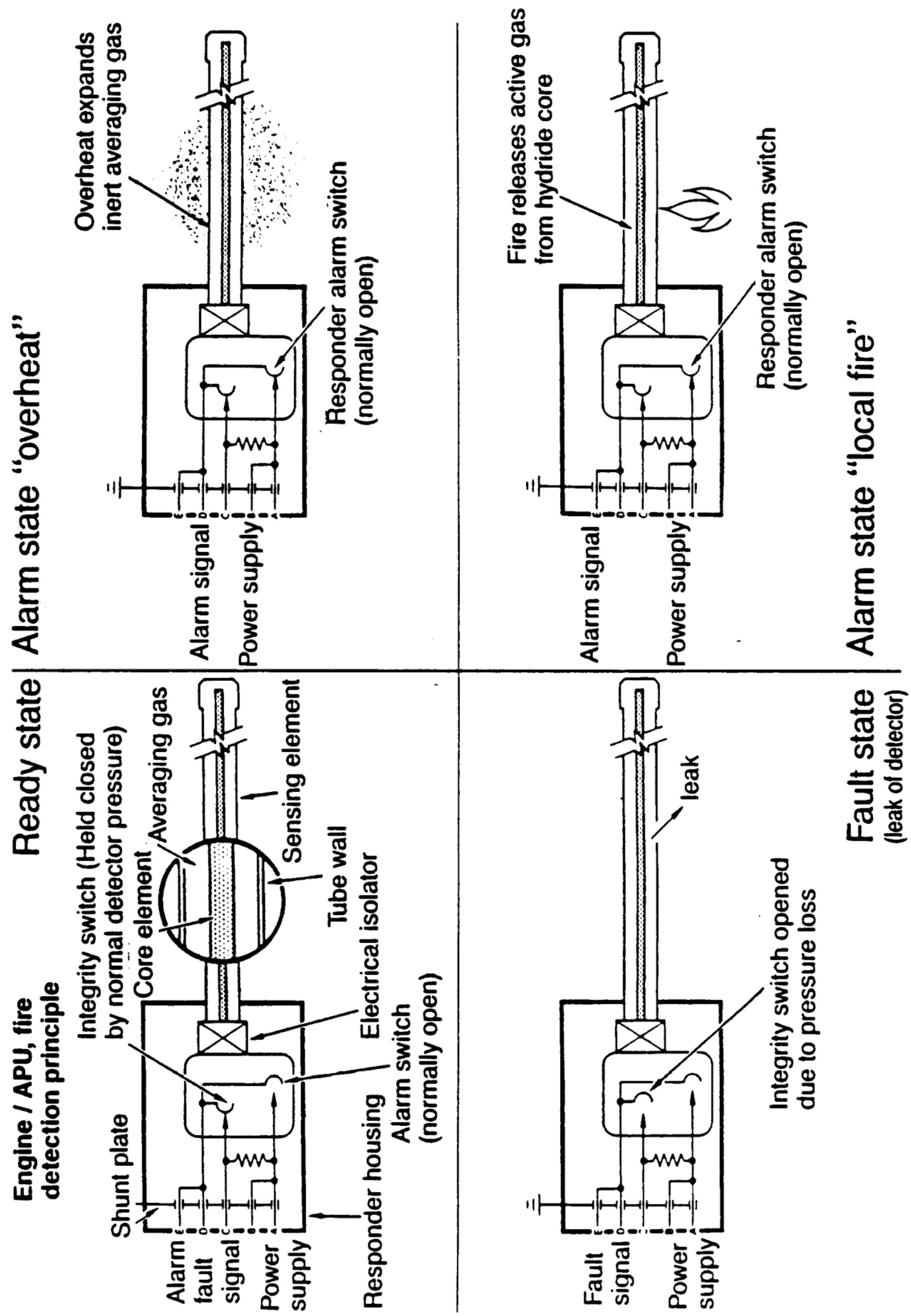


Figure 4.4 The fire detection loops with sensing element and responder in alarm and fault state (Technical Definition A320 ATA26)

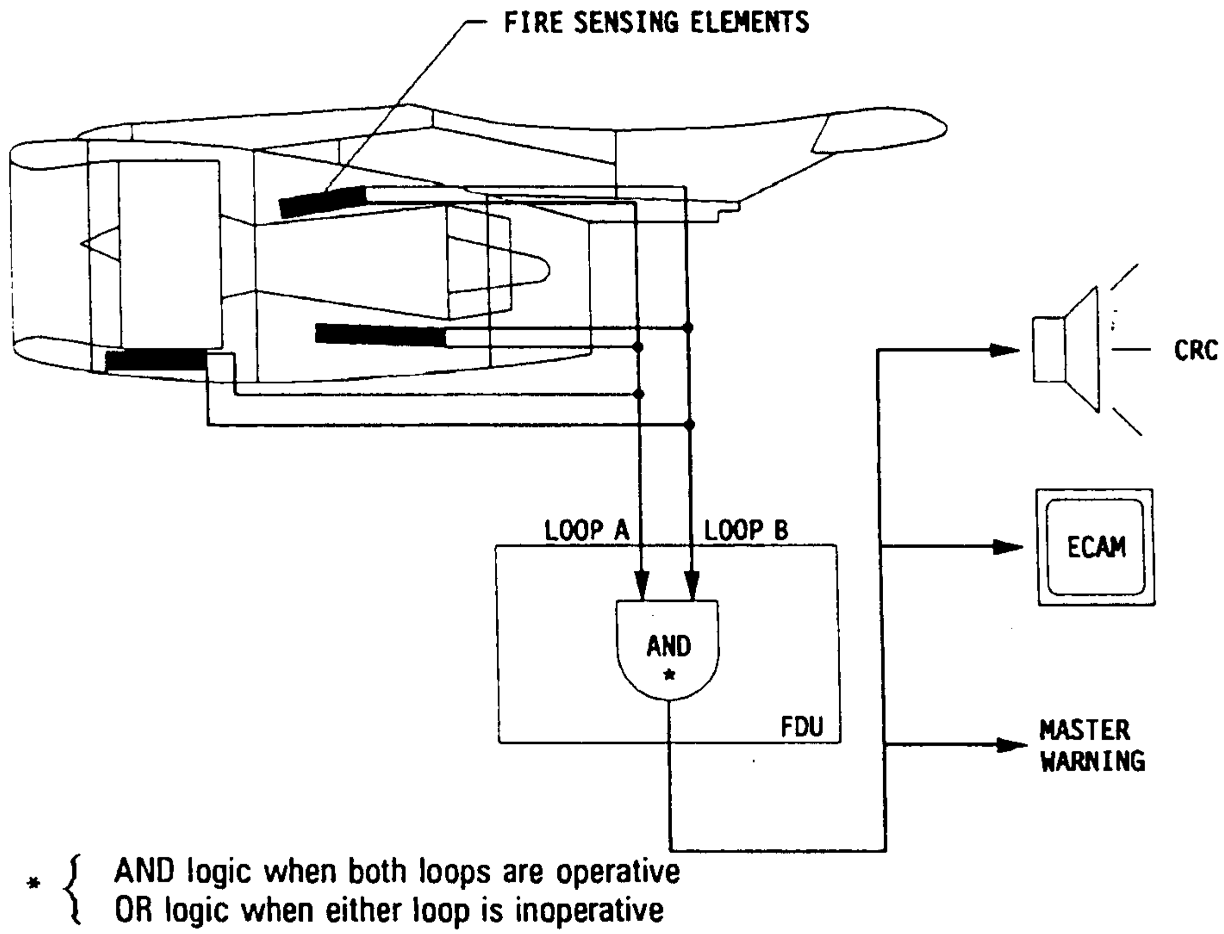


Figure 4.5 Engine fire detection logic (FCOM A320 ATA 26)

The **ENG/APU FIRE panel** includes the ENG 1(2) FIRE push button switch and a TEST push button switch for each engine.

The ENG 1(2) FIRE pushbutton switch can be pushed only if the safety guard is open. Each push button switch has three main functions:

- indicate the FIRE warning generated by the Fire Detection Unit,
- activate the micro switches involved in the extinguishing procedure, and
- arm the discharge function for bottles 1 and 2.

TEST push button switch checks the condition of the:

- fire detectors (loops A and B), Fire Detection Unit (FDU), indications, warnings and associated wirings (loop test),
- percussion cartridge filaments of the fire extinguisher bottles and associated wiring (squib test).

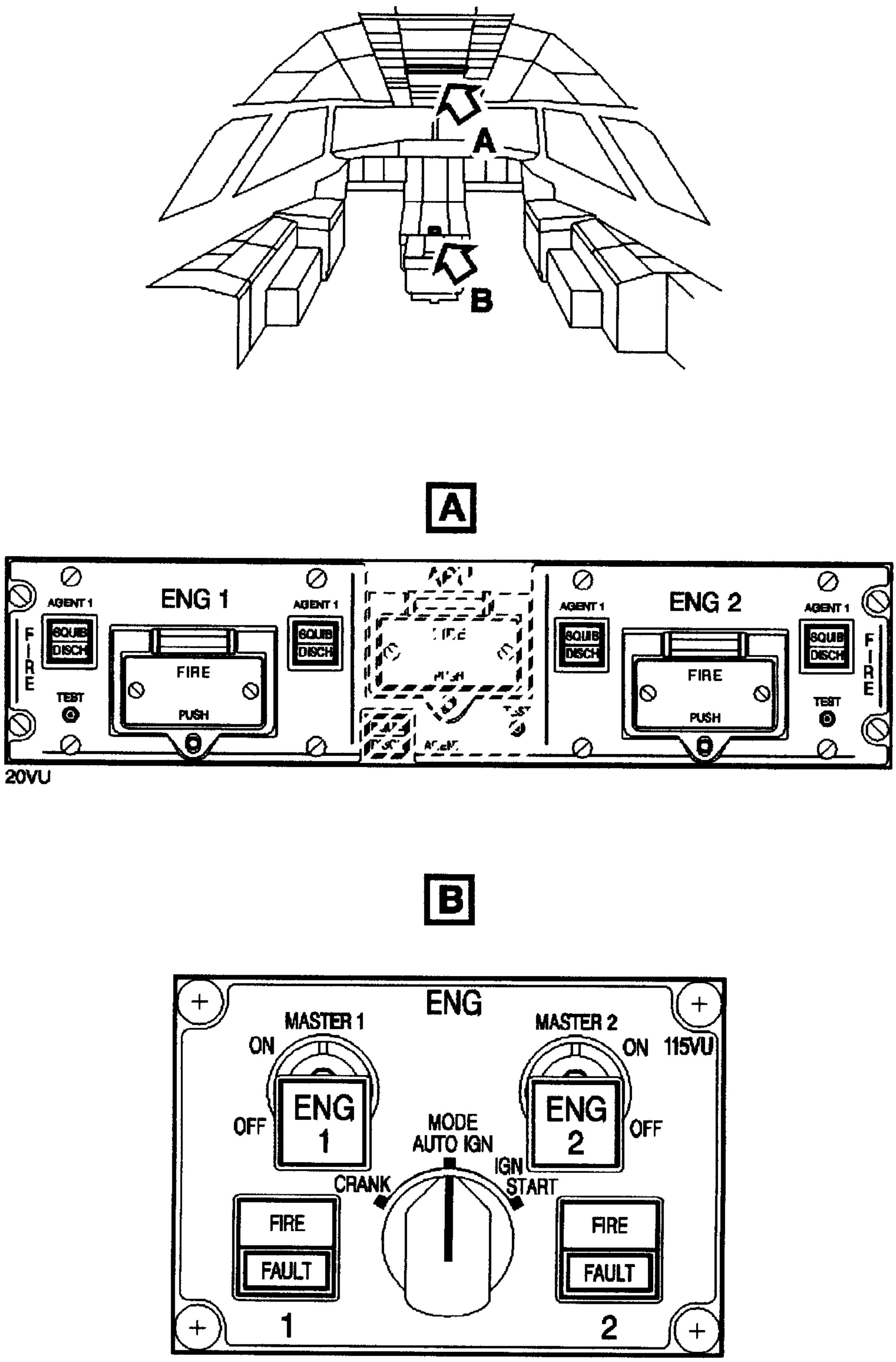


Figure 4.6 Engine fire indications and controls (AMM A321 ATA 26-00)

Fire Extinguishing System

General: The fire extinguishing system is activated when fire is detected by the fire and overheat detection system (see above). The system has two main functions:

- to extinguish at its early stage any fire occurring in the nacelle protected zones.
- to prevent engine fire from spreading: the engine is isolated from the rest of the aircraft; the various supplies such as hot air, fuel, hydraulics, electrical power are closed for this purpose.

The engine fire extinguishing system comprises for each engine:

- on the ENG/APU FIRE panel:
  - one ENG 1(2) FIRE push button switch,
  - two AGENT push buttons (AGENT 1 and AGENT 2) with a white integral light SQUIB and an amber light DISCH,
  - one TEST push button switch,
- two fire extinguisher bottles located in the engine pylon,
- the fire extinguishing distribution system consisting of the extinguishing lines routed in the pylon and leading to the nacelle and the outlet nozzles.

Principle: For each engine, two fire **extinguisher bottles** contain fire extinguishing agent. The fire extinguisher bottles located in the aft section of the engine pylon are connected to the **extinguishing lines**. This system is routed in the pylon and leading to the nacelle. The fire extinguisher bottles are controlled from the cockpit. Their firing is possible only if the **ENG 1(2) FIRE push button switch** is already pushed in. During the extinguishing procedure, the extinguishing agent flows into the rigid pipes and is sprayed in the engine protected zones: the fan and the core compartments. Thirty seconds after the first bottle discharged (if the fire is still present) the pilot fires the second bottle. The fire extinguishing procedure is given by the ECAM display unit.

The **fire extinguisher bottle** is made up of

- a spherical container with extinguishing agent
- a discharge head
- a cartridge.

The **spherical container**:

- number of outlet ports: 1,
- volume: 6230 cm^3,
- filling pressure: 41,4 bars at 21°C

In the spherical container there is a **fire extinguishing agent**

- type: Halon 1301 (bromotrifluoromethane, CF3 Br),
- quantity: 5 kg,
- pressurized by nitrogen (N2), quantity 0.20 kg.

On the spherical container there is

- a pressure switch
- a filling fitting
- an outlet port with a frangible disc.

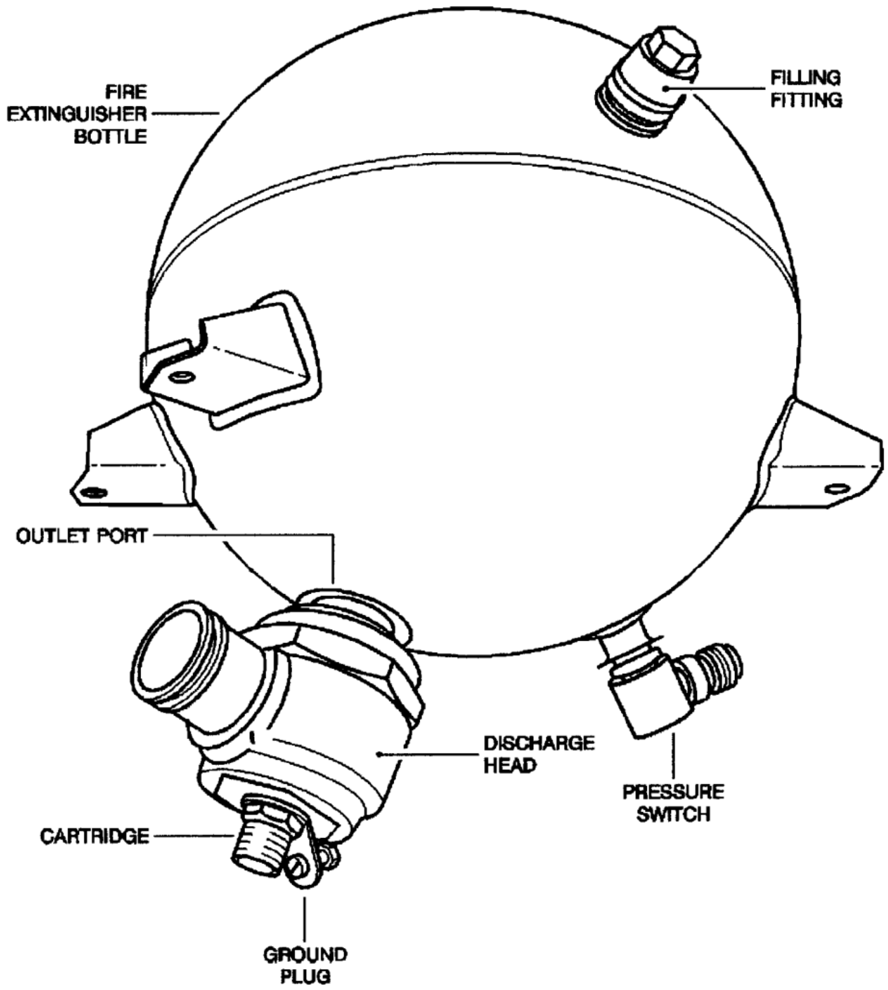


Figure 4.7 A fire extinguisher bottle (AMM A321 ATA 26-21)

The **outlet port** of the spherical container is located in the lower section of the container. The **pressure switch** monitors when the bottle is discharged or has a leakage. The pressure switch is electrically connected to the ENG/APU FIRE panel which generates a discharge signal to the DISCH light. The pressure switch fitted on the fire extinguisher bottle can be tested manually. The fire extinguisher bottle can be filled through the **filling fitting** assembly. Firing of the cartridge causes rupture of the **frangible disc** (a calibrated metallic membrane) installed on the outlet port. The fire extinguishing agent is then discharged into the **fire extinguishing distribution system**. The frangible disc also functions as an overpressure device in case of excessive pressure in the fire extinguisher bottle. The electro-pyrotechnic **cartridge** contains 400 mg of explosive powder. The powder is fired by two filaments supplied with 28V DC. Each filament can supply the electrical power necessary to the firing if the other filament fails.

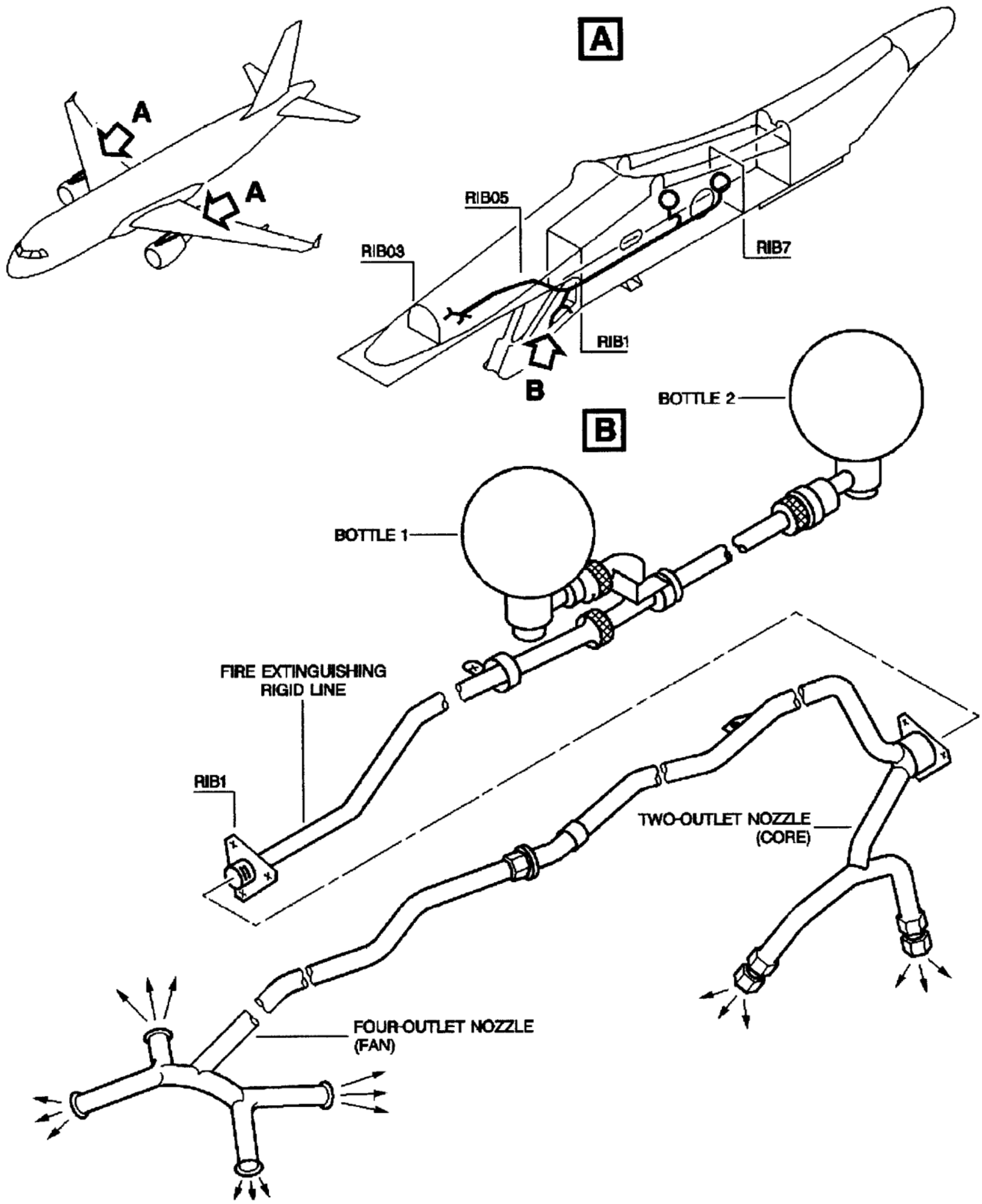


Figure 4.8 The engine fire extinguishing distribution system (AMM A321 ATA 26-21)

The **fire extinguishing distribution system** for each engine consists of the extinguishing lines and the outlet nozzels. The spherical containers are connected to a stainless steel rigid pipe. The fire **extinguishing line** is routed in the primary structural box of the engine pylon up to rib 1. From rib 1 the line is divided into two segments directed to the engine core and fan compartments. The end of the fire extinguishing line in the core compartment (above the combustion chamber) has a two **outlet nozzles** which sprays the core compartment. From rib 1, the fan segment is routed below the upper spar of the engine pylon up to the upper section of the fan frame. The end of the fire extinguishing line has four outlet nozzles which spray the fan compartment.

Engine fire extinguishing procedure: The list of actions to be done during the fire extinguishing procedure comes into view automatically on the ECAM display unit at the same time as the FIRE warnings. As soon as the required actions are done, the corresponding line is canceled automatically on the ECAM display unit. The following procedure must be applied:

THR LEVER 1	IDLE	Throttle control lever in the Idle position
ENG MASTER 1.............................	OFF	ENG/MASTER switch in the OFF position
ENG 1 FIRE P/B.............................	PUSH	Push the ENG/FIRE push button switch
AGENT 1 AFTER 10 S...................	DISCH	Wait 10 seconds for optimum extinguishing procedure
AGENT 1	DISCH	Squib the fire extinguisher bottle 1
ATC	NOTIFY	Send a distress signal to Air Traffic Control (ATC)
IF FIRE AFTER 30 S: AGENT 2	DISH	The second fire extinguisher bottle is fired, if the FIRE legend is still ON

4.3 APU Fire Detection and Extinguishing

General: The APU fire detection system operates on the pneumatic principle. It detects and indicates a fire or overheat condition in the APU compartment with two independent fire detection loops. The APU fire extinguishing system extinguishes fires detected in the APU compartment. In flight, the crew must operate the system manually from the cockpit. On the ground, the fire and overheat detection system activates the extinguishing system automatically. *One* fire extinguisher bottle contains the fire extinguishing agent.

The APU fire detection and extinguishing system follows the principles of the engine fire detection and extinguishing system. Therefore, details common to both systems are omitted here, but differences to the engine fire detection and extinguishing will be elaborated.

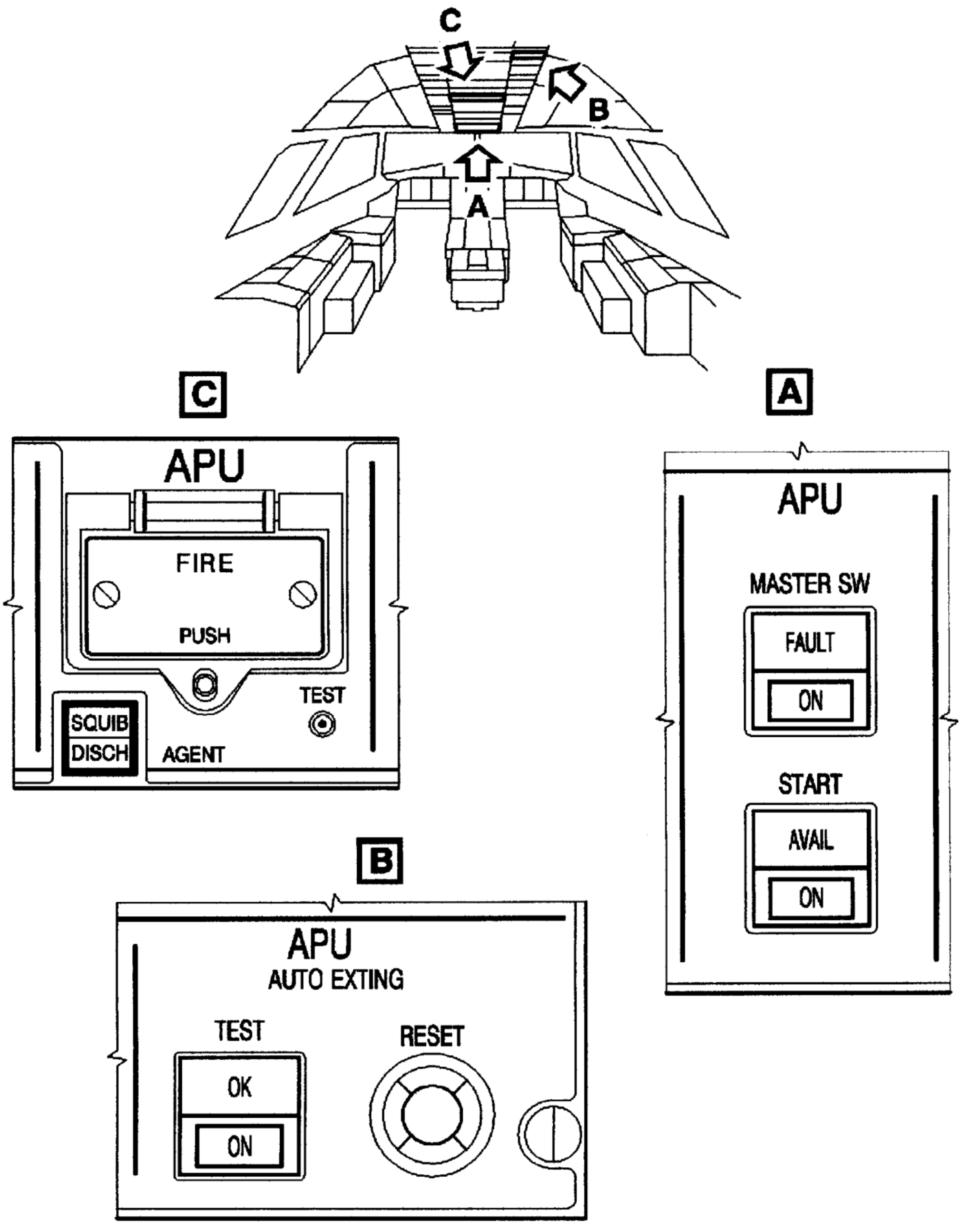


Figure 4.9 The APU fire indications and controls on the overhead panel (AMM A321 ATA 26-00)

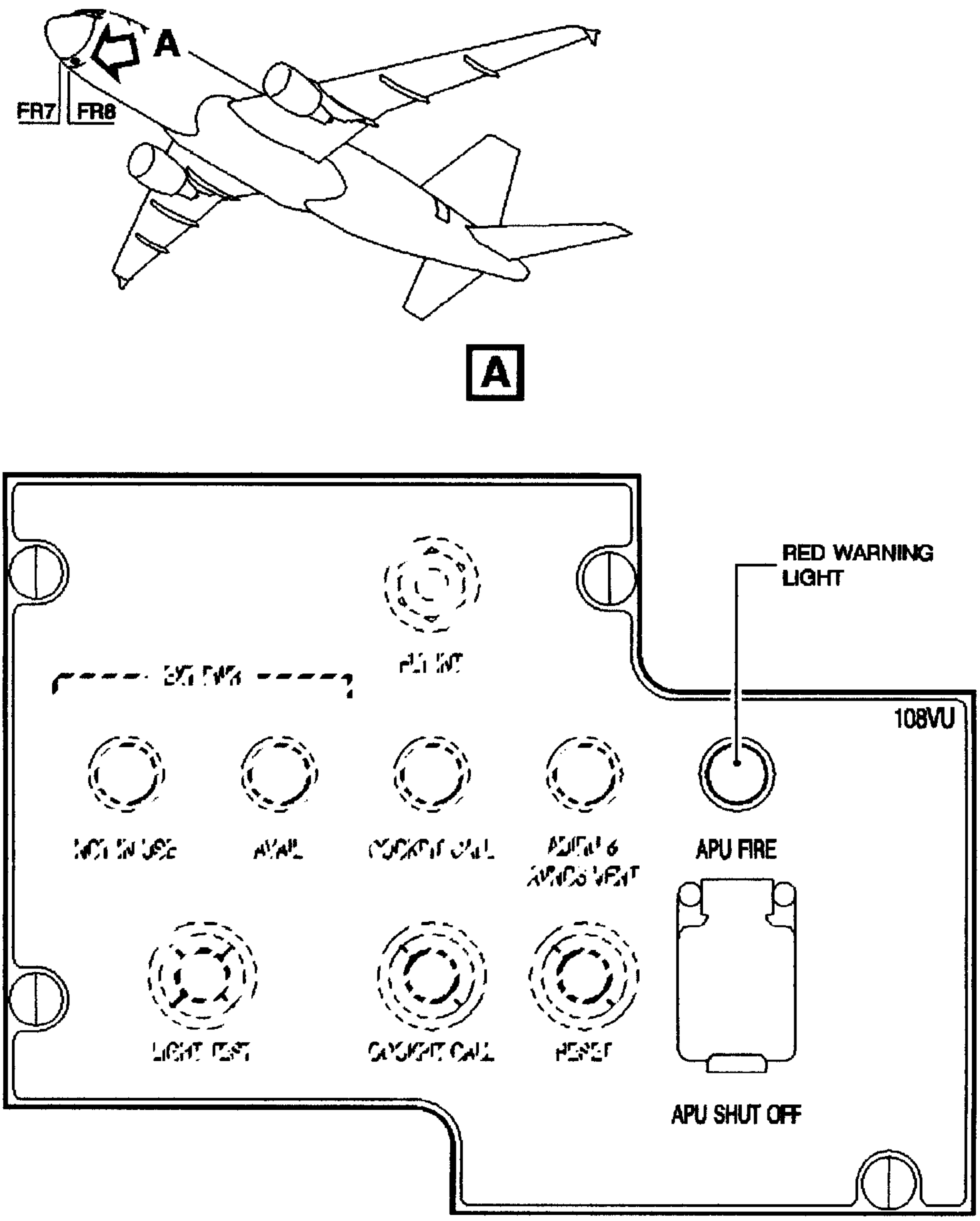


Figure 4.10 The APU fire indications and controls at the nose landing gear (AMM A321 ATA 26-00)

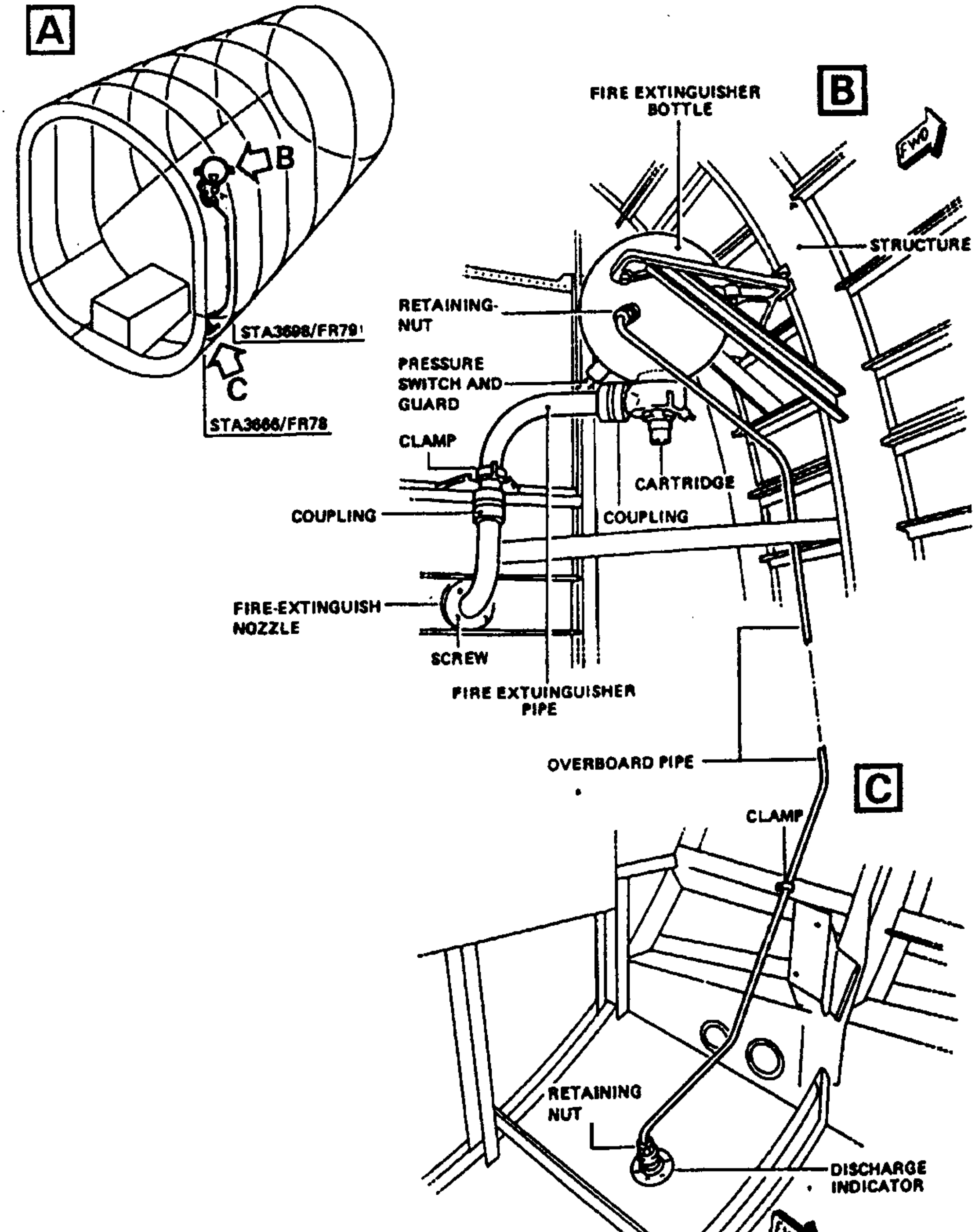


Figure 4.11 The APU fire extinguishing system.
(DLH Technical Training Manual A319/A320/A321 Level 3 ATA 26, p.84)

The APU detection system comprises two identical (electrically independent) fire detection loops (A and B). They are installed in the APU compartment adjacent to critical components as

- fuel lines,
- starter generator,
- fuel control unit (FCU),
- ignition box,
- turbine plenum.

The middle part of the ENG/APU FIRE panel on the cockpit overhead panel is related to the APU fire detection and includes

- an APU FIRE guarded push button with a red integral warning light,
- a TEST push button for a manual system test,
- an AGENT push button with a white integral light SQUIB and an amber light DISCH.

APU fire warnings on the ground appear

- on the fire control panel: the red light in the APU FIRE push button switch flashes,
- on the glareshield panels: the red light in the two MASTER WARNING push buttons flash,
- on the ECAM upper display unit the **APU fire extinguishing procedure** is shown:
  APU FIRE
  APU FIRE P/B .... PUSH
  MASTER SW............................. OFF
- outside the aircraft: a horn sounds,
- in the flight compartment: a continuous repetitive chime (CRC) sounds.

The APU fire extinguishing system is activated when the fire and overheat detection system detects a fire. For the APU, the fire extinguishing agent is contained in one fire extinguisher bottle. During the extinguishing procedure, the extinguishing agent flows in rigid pipes and is immediately sprayed in the APU compartment. In flight, the extinguishing system is manually activated from the cockpit. On the ground, the fire and overheat detection system activates the extinguishing system automatically (if there is no action from the cockpit).

4.4 Avionic Smoke Detection

There are two types of smoke detection

- the direct detection by the crew,
- the secondary detection by a smoke detector.

The avionic smoke detection system with a smoke detector - which is explained here - is only supporting the awareness of the crew and confirms that there is smoke in the avionics compartment.

The **avionics-compartment smoke detection system** includes one smoke detector installed on the air extraction duct. The smoke detector triggers the smoke warnings to the cockpit when the alarm threshold is reached. When there is smoke, pneumatic and electrical procedures are started.

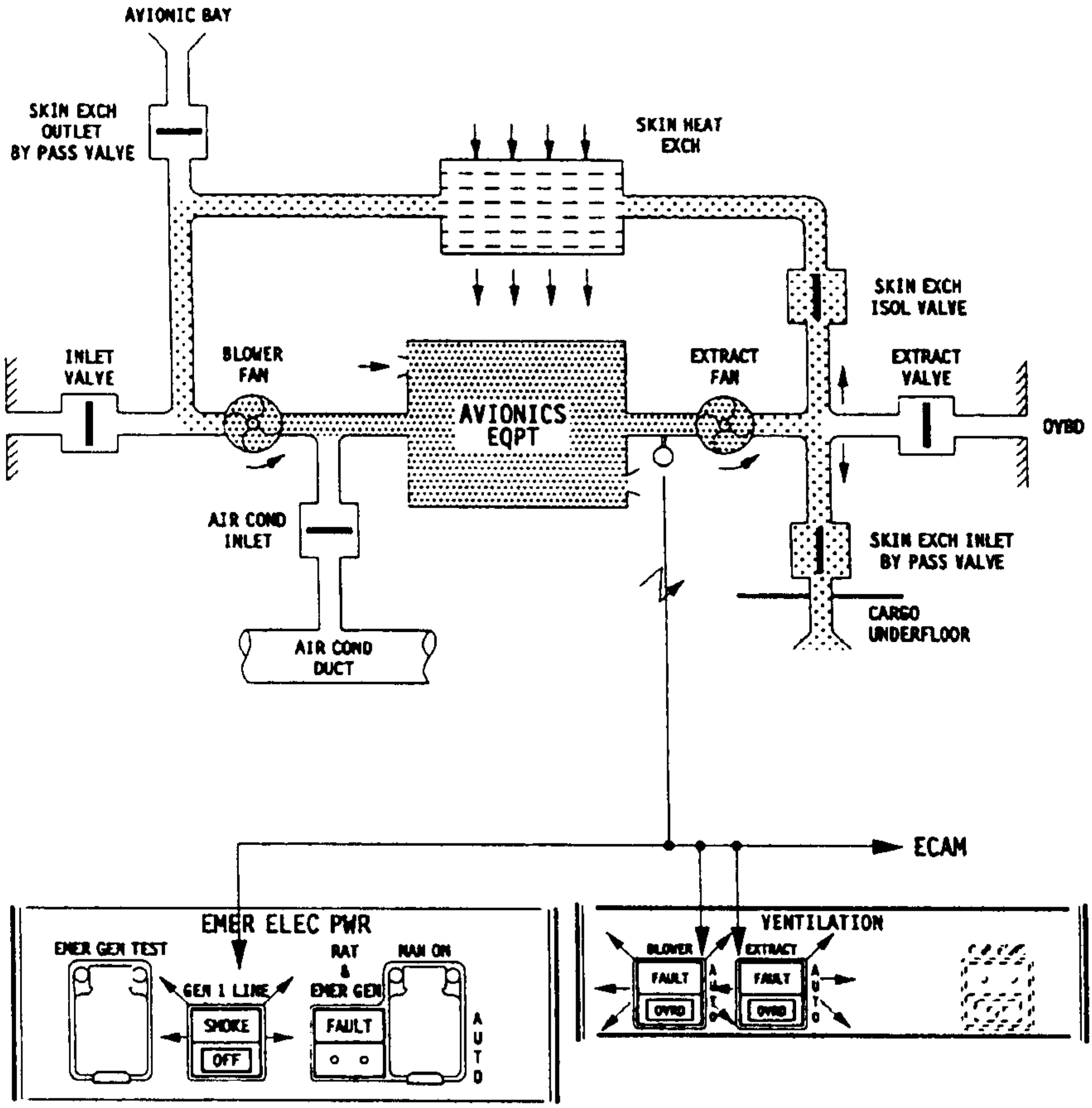


Figure 4.12 The avionic smoke detection system schematic (FCOM A320 ATA 26)

The **smoke detector** includes:

- a protective box with air inlets and electrical connectors,
- a measuring chamber with a detection cell (which contains a radio-active source and electrodes) and an electronic circuit board which analysis the information from the measuring chamber.

The air entering the measuring chamber between two electrodes is ionized by a source of extremely low radioactivity. When smoke gas gets between the electrodes, it causes a variation of the current in the circuit as depicted in the Figure.

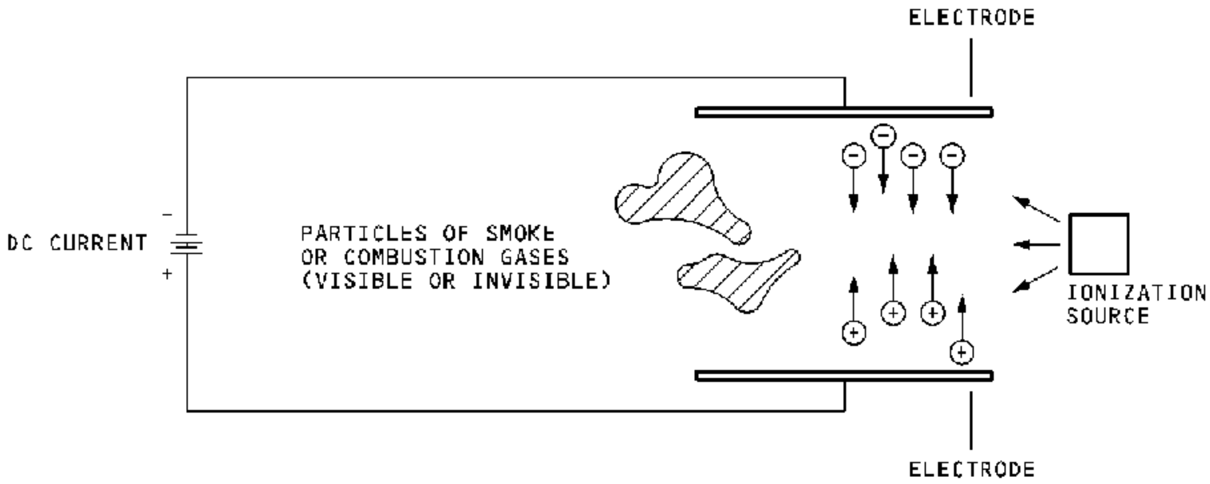


Figure 4.13 Smoke detection principle (AMM A321 ATA 26-17)

When the smoke concentration is above the alarm threshold, the smoke detector triggers the smoke warnings in the cockpit:

- on the EMER ELEC PWR section of the panel the SMOKE light illuminates,
- on the VENTILATION overhead panel the BLOWER FAULT and EXTRACT FAULT light illuminate,
- the MASTER CAUT lights illuminate on the glareshield,
- a warning message is shown on the upper ECAM display unit (i.e. the E/WD),
- the aural warning sounds with a single chime.

When this happens, you must push the VENTILATION/BLOWER push button switch and the VENTILATION/EXTRACT push button switch: the OVRD legends come on. This causes the *blower fan* to stop, opens the *air conditioning inlet valve* and opens the *skin air outlet valve* not fully. All other valves close and the air goes overboard through the skin air outlet valve. The extract fan stays energized.

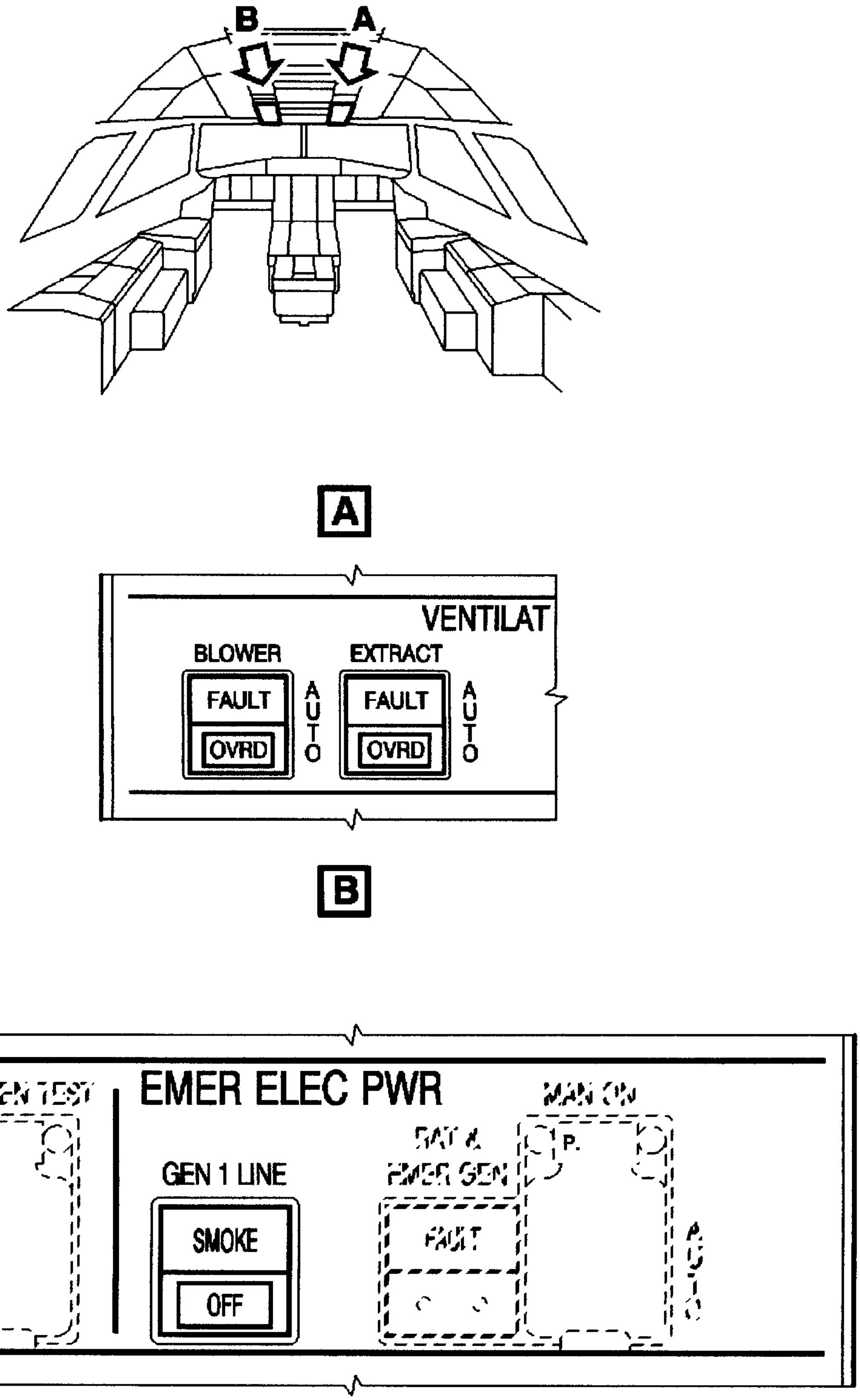


Figure 4.14 Avionic compartment smoke detection and controls (AMM A321 ATA 26-00)

Avionics compartment smoke procedure: The list of the necessary actions during the smoke procedure comes into view automatically on the lower ECAM display unit while the SMOKE warnings are triggered. When these actions are completed, the related lines are canceled automatically on the lower ECAM display unit. The procedure below must be applied:

IF PERCEPTIBLE SMOKE

OXY MASK/GOGGLES..................	ON	
CAB FANS......................................	OFF	to keep smoke off the cockpit and cabin
BLOWER..	OVRD	(see above)
EXTRACT.......................................	OVRD	(see above)

An electrical procedure is applied to eliminate the cause of the smoke if the smoke emission persists more than 5 minutes.

IF SMOKE AFTER 5MNS:

GEN 1 LINE...............................	OFF	on EMER ELEC PWR overhead panel
EMER ELEC PWR	MAN ON	on EMER ELEC PWR overhead panel: Ram Air Turbine extension

4.5 Cargo Compartment Smoke Detection and Extinguishing

General: The **cargo compartment smoke detection system** gives a visual and aural warning in the cockpit, if smoke or fire is in the compartment. It is a dual loop system to prevent incorrect warnings. Four smoke detectors are installed in the FWD compartment and six smoke detectors in the AFT, with an AND-logic. The **cargo compartment fire extinguishing system** is a single-shot system with one extinguisher bottle for both FWD and AFT cargo compartments.

Smoke Detection System

The cargo compartment smoke detection system comprises:

- the smoke detectors,
- Smoke Detection Control Unit (SDCU),
- the smoke annunciator lights and a TEST push button switch.

The **smoke detectors** ionize the air particles that pass between two electrodes. When smoke gas gets between the electrodes, it causes a variation of the current in the circuit. At a certain level of smoke, the detector transmit a warning signal to the SDCU.

The **Smoke Detection Control Unit** (SDCU) controls the lavatory and cargo-compartment smoke-detection system. The SDCU has two channels, which make it a fail-safe unit. The system will operate normally if one channel fails. The Built In Test Equipment (BITE) detects and isolates failures in the SDCU. It also makes sure that the smoke detectors function correctly. Most of the system functions are monitored continuously. Information of faulty equipment is signaled to the CFDS.

A FWD **SMOKE annunciator light** and an AFT SMOKE annunciator light are installed on the cargo smoke panel. Upon signal from the SDCU, the related SMOKE annunciator light comes on.

The *Press-to*-Test (**PTT**) **push button** switch together with the SDCU, permits a functional test of the cargo smoke detection system. The (PTT) push button switch is installed between the smoke annunciator lights on the cargo smoke panel.

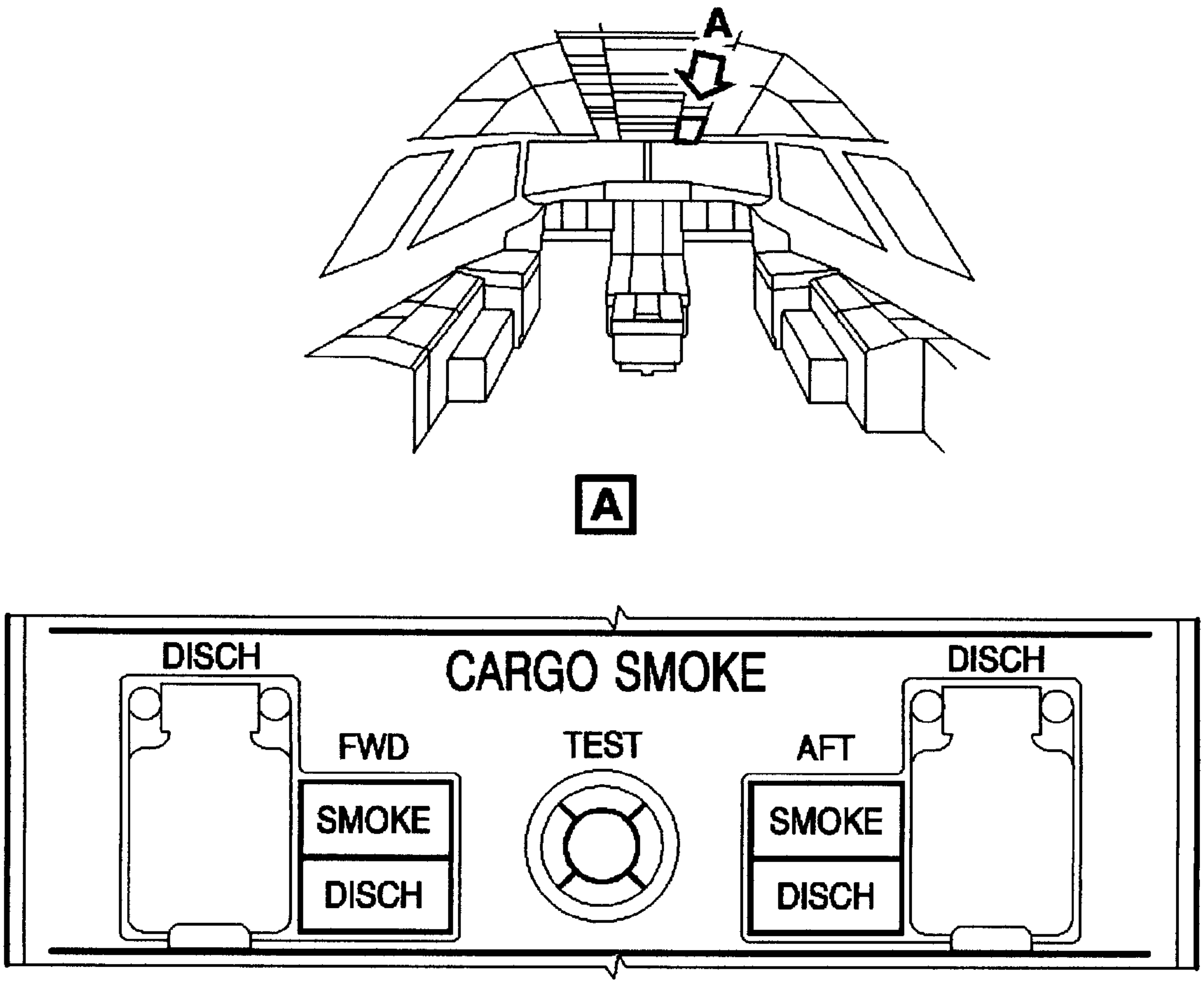


Figure 4.15 The cargo compartment smoke indications and controls on the overhead panel (AMM A321 ATA 26-00)

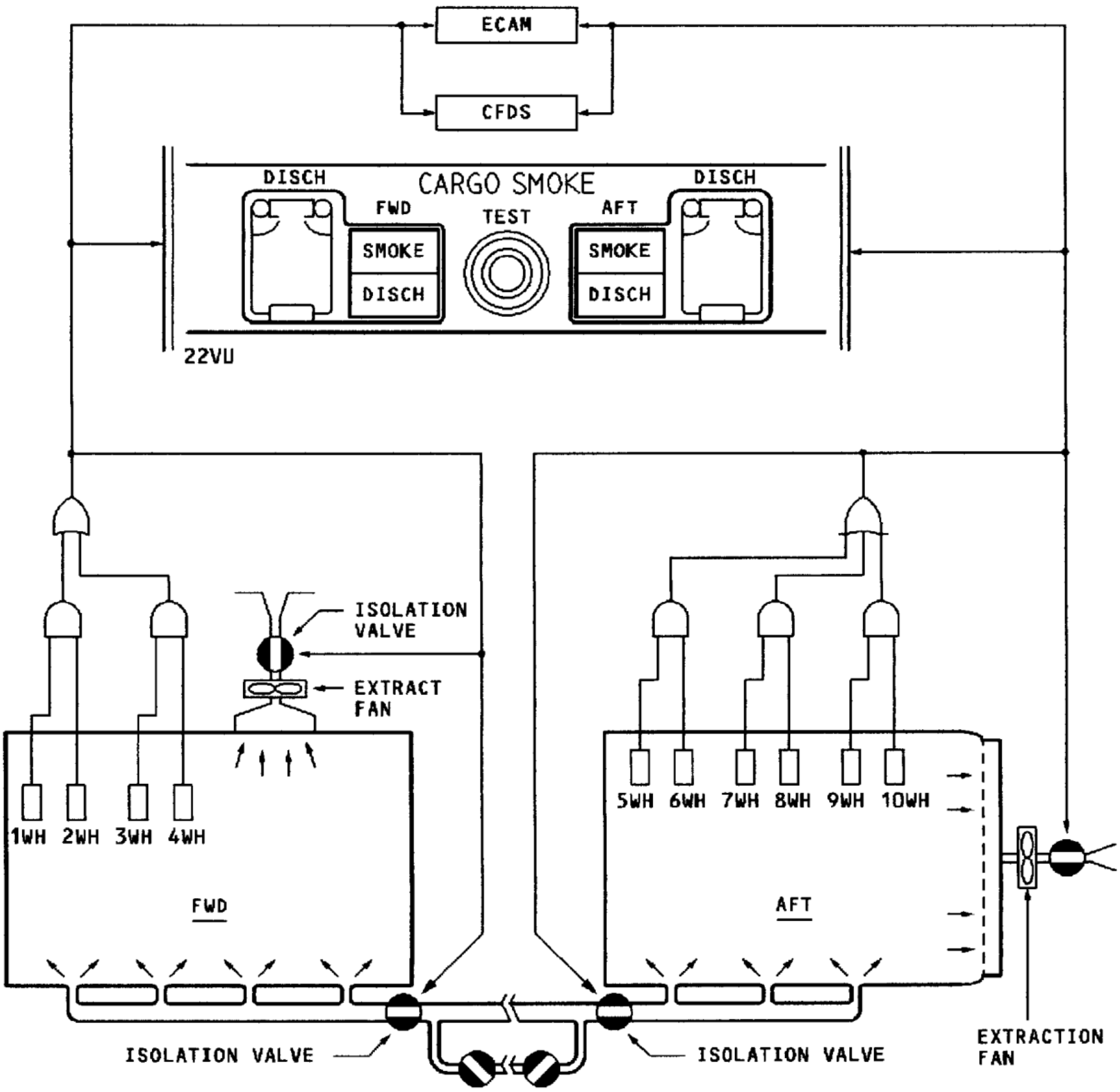


Figure 4.16 Cargo compartment smoke detection system schematic (AMM A321 ATA 26-16)

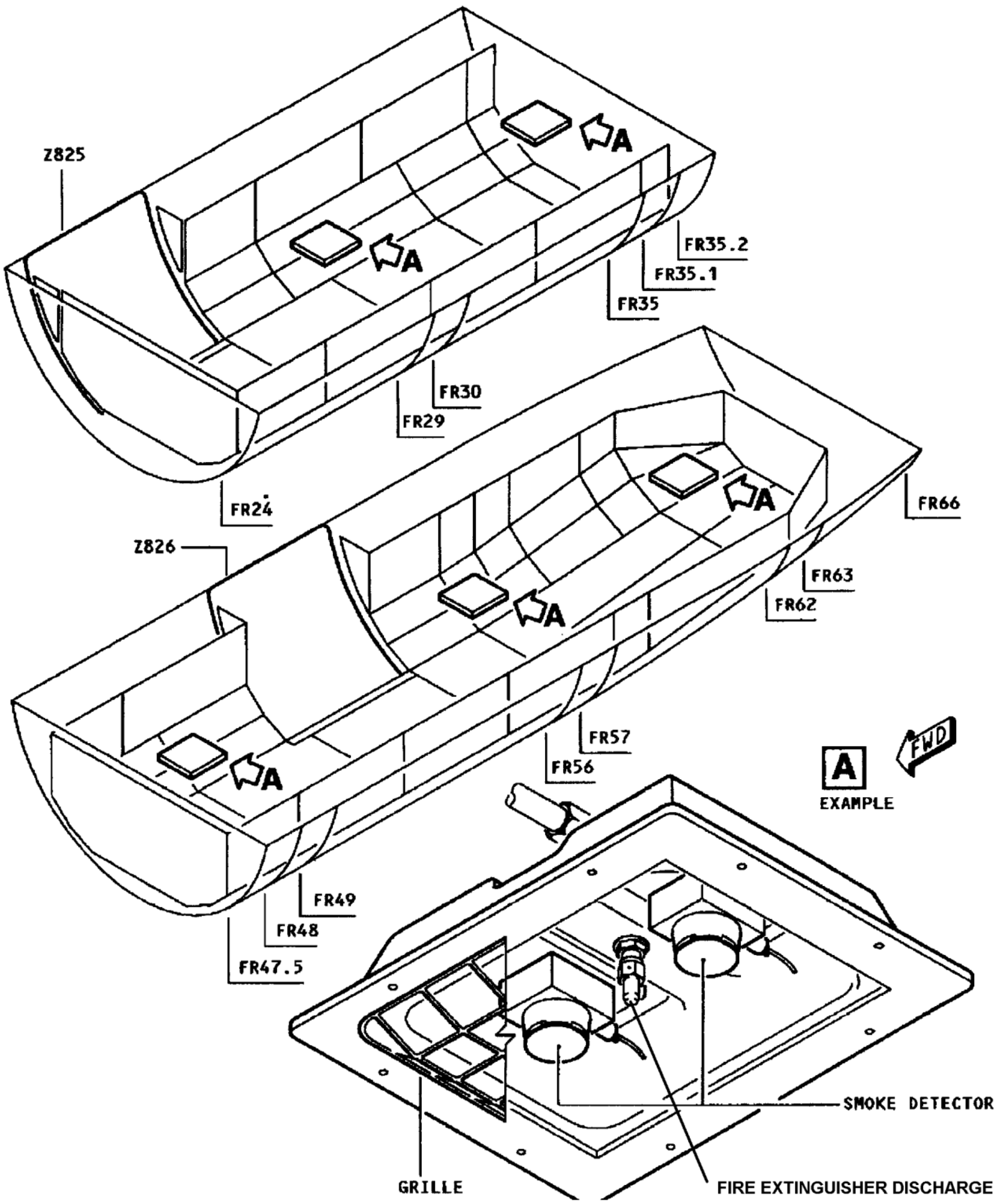


Figure 4.17 Cargo compartment smoke detection and extinguishing component location (AMM A321 ATA 26-16)

Operation: Smoke detected in the cargo compartment will cause:

- the respective SMOKE warning light to come on,
- the red light in the MASTER WARNING pushbutton switch to flash,
- the aural repetetive chime to sound,
- the ECAM upper display unit to show the messages:
  - SMOKE FWD/AFT CARGO SMOKE
  - ISOL VALVE (of affected compartment) ... OFF (if not automatically closed)
  - AGENT ... DISCH .

In the case of a smoke warning the isolation valves of the cargo-compartment ventilation system close automatically. They remain closed independently of the smoke warning signals.

Extinguishing System

The cargo compartment fire extinguishing system comprises

- one fire extinguisher bottle
- two cartridges
- two fire extinguisher pipes
- two push button switches to activate the system,
- two SMOKE/DISCH indication lights,
- one Smoke Detection Control Unit (SDCU).

Principle: The cargo-compartment fire-extinguishing system has one fire extinguisher bottle for the FWD and AFT cargo-compartments. One cartridge is installed for the FWD cargo-compartment and one for the AFT cargo-compartment. Electrically-detonated cartridges fire the extinguisher bottle. A pressure switch is attached to the bottle. It monitors the discharge of the bottle. A safety relief device is attached to the bottle to prevent a pressure increase. One fire extinguisher pipe connects the bottle with the FWD discharge nozzle and one pipe with the two nozzles in the AFT cargo-compartment.

Operation: If a smoke warning occurs, you have to lift the guard and to push the related DISCH push button switch. The cartridge at the bottle outlet detonates and the agent discharges into the applicable cargo compartment. The contacts of the bottle pressure switch open and give a signal to the SDCU and the relay. The relay opens and closes a contact to the related DISCH indicator light. The light comes on. The SDCU also gives a signal to the Flight Warning Computer (FWC) and CFDS. The FWC changes the ECAM upper display to AGENT DISCH. The CFDS stores the low-pressure data.

4.6 Lavatory Smoke Detection and Extinguishing

General: A **lavatory smoke detection system** is installed to detect smoke and/or fire in the lavatories. If smoke is detected, the system gives a visual and aural warning to the crew and in the cabin. The **lavatory fire-extinguishing system** is installed in each lavatory service cabinet. Each lavatory fire-extinguishing system has an extinguisher bottle which is self-actuated. The bottle discharges its agent automatically when heat activates it. An inert gas floods the lavatory service cabinet and extinguishes the fire. Any fire in the waste is kept within the confines of the metal waste-paper bin.

Smoke Detection System

The lavatory smoke detection system is made-up of

- one smoke detector for each lavatory,
- the Smoke Detection Control Unit (SDCU).

The **smoke detectors** ionize the air particles that pass between two electrodes. When smoke gas gets between the electrodes, it causes a variation of the current in the circuit. At a certain level of smoke, the detector transmit a warning signal to the SDCU.

Smoke Detection Control Unit (SDCU) is a common unit for the cargo compartment and lavatory. For details see: "cargo smoke detection and extinguishing".

Smoke or fire in one of the lavatories causes a detector to signal the SDCU. The SDCU sends signals to the Centralized Intercommunication Data System (CIDS) and the Flight Warning Computer (FWC). Smoke warnings are given in the cockpit and the cabin.
The cockpit warnings are:

- a repetitive chime,
- a red master warning light,
- a smoke warning indication on the ECAM upper display unit.

The cabin warnings are:

- a triple chime from all cabin loudspeakers with a repetitive time of approx. 30 s,
- an amber flashing light on the respective Area Call Panel (ACP),
- a common red lavatory smoke indicator on the FWD attendant panel.

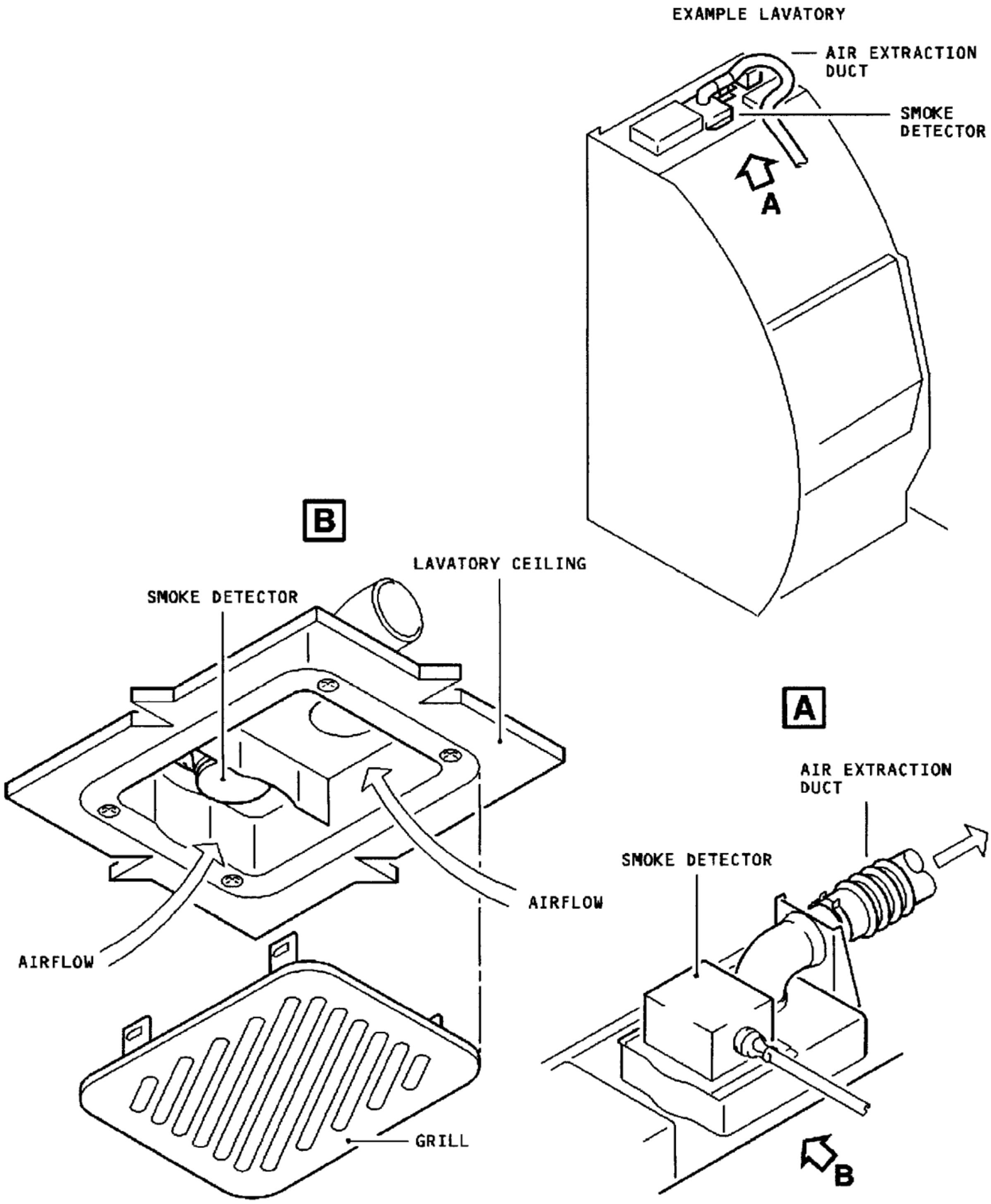


Figure 4.18 Lavatory smoke detection components and location (AMM A321 ATA26-17)

Extinguishing System

The lavatory fire-extinguishing system is completely automatic and self-contained. A fire or overheat condition opens the release mechanism. When the temperature in the wastepaper bin area is approx. 79°C, the fusible material in the tip of the discharge tube melts. The lavatory fire extinguisher then discharges completely within 3 to 15 s. Each unit weighs 0.450 kg. It stores and discharges 100 to 130 g of Halon 1301 into the wastepaper bin to extinguish the fire.

Each fire extinguisher comprises

- a spherical container (60 mm in diameter),
- a fill port with a fill valve,
- a discharge tube with a fusible plug,
- a pressure gage.

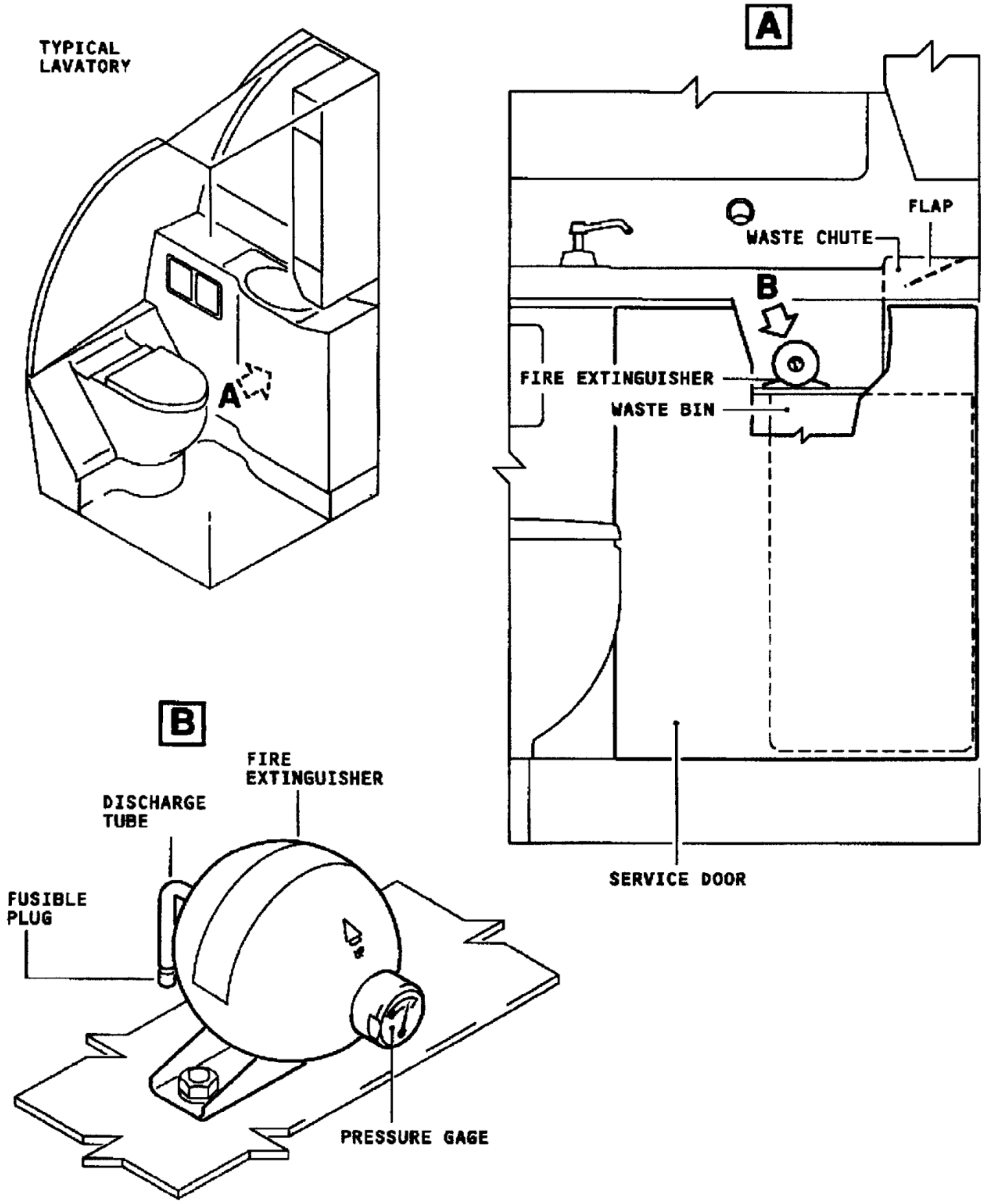


Figure 4.19 Lavatory fire extinguishing components and location

5 Selected Issues in Aircraft Fire Protection

5.1 Detailed ATA Breakdown for Fire Protection Systems

The ATA iSpec 2200 (**ATA 2200**) includes a breakdown and definitions for the fire protection system and its subsystems:

```
26 FIRE PROTECTION
Those fixed and portable units and components which detect and indicate fire
or smoke and store and distribute fire extinguishing agent to all protected
areas of the aircraft; including bottles, valves, tubing, etc.

-00 General

-10 Detection
That portion of the system which is used to sense and indicate the presence
of overheat, smoke, or fire.

-20 Extinguishing
That portion of those fixed or portable systems which is used to extinguish
fire.

-30 Explosion Suppression
That portion of the system which is used to sense, indicate and extinguish a
flame propagating into the fuel vent or scoop to prevent an explosion in the
fuel system.
```

5.2 Companies in the Field of Aircraft Fire Protection

Kidde Aerospace and Defense Companies
http://www.kidde.aero/Contact+Details.shtml

Kidde Aerospace / Fenwal Safety Systems.
Fenwal was recently consolidated with Kidde Aerospace in Wilson, NC.
Phone: 252-237-7004
Fax: 252-246-7181
http://www.kiddeaerospace.com
Email: salesinfo@kiddeaerospace.com

Kidde Graviner in London England
Phone: (44) (0) 1753 683245
Fax: (44) (0) 1753 685126
http://www.kiddegraviner.com
email: victoria.kay@kiddegraviner.co.uk

Kidde Dual Spectrum in Goleta,CA
Phone: (805) 961 0555
Fax: (805) 685 8227
http://www.safebus.net
Email: Sales.info@dualspectrum.com

Kidde-Deugra Brandschutzsysteme GmbH
http://www.kidde-deugra.com

L'Hotellier
Paris, France
http://www.lhotellier.net

Siemens Cerberus Guinard
http://www.sibt.com/fs/content/10/10_010en.htm

Curtiss-Wright Controls, Inc.

12701 Schabarum Avenue
Irwindale, CA 91706
(626) 851-3100 Main
(626) 960-8500 Fax
http://www.autronics.com/prodsys/fireprot.html

Honeywell
http://www.honeywell.com/sites/aero/
http://www.honeywell.com/sites/aero/Products_Services.htm
http://www.fenwal.com
http://content.honeywell.com/sensing/products/thermalhumidity/

Meggitt Safety Systems
http://www.meggittsafety.com/

Fire Fighting Enterprises Ltd
9 Hunting Gate
Wilbury Way
Hitchin
Hertfordshire
SG4 0TJ
United Kingdom
http://www.ffeuk.com

Pacific Scientific
http://www.pacificscientific.com/

AOA Apparatebau Gauting GmbH
Ammerseestraße 45 - 49
D - 82131 Gauting
Telefon: +49 (0)89 / 8 93 17-0
Telefax: +49 (0)89 / 8 93 17-215
Mail: info@aoa-gauting.de
http://www.aoa-gauting.de
http://www.aoa-gauting.de/prod_24.html

"Unentbehrlich für die Sicherheit der Passagiere in Flugzeugen und Schienenfahrzeugen sind die Rauchmeldesysteme von AOA. Unsere Ionisationsrauchmelder und unsere optischen Rauchmelder sind mikroprozessorgesteuert. Die Rauchmeldesysteme sind auf dem neuesten Stand der Technik."

5.3 Operational Requirements on Fire Protection

In addition to the certification requirements **JAR-25/CS-25** and **FAR Part 25** (see Chapter 2) also requirements for flight operation provide some details on fire protection.

FAR Part 125

FAR Part 125 (http://ecfr.gpoaccess.gov) gives details about:

§125.119 Fire precautions
§125.151 Powerplant fire protection
§125.161 Fire-extinguishing systems
§125.163 Fire-extinguishing agents
§125.165 Extinguishing agent container pressure relief
§125.167 Extinguishing agent container compartment temperature
§125.169 Fire-extinguishing system materials
§125.171 Fire-detector systems
§125.173 Fire detectors

§125.163 Fire-extinguishing agents is reproduced here:

Electronic Code of Federal Regulations (e-CFR)

BETA TEST SITE

e-CFR Data is current as of April 6, 2006

Title 14: Aeronautics and Space
PART 125—CERTIFICATION AND OPERATIONS: AIRPLANES HAVING A SEATING CAPACITY OF 20 OR MORE PASSENGERS OR A MAXIMUM PAYLOAD CAPACITY OF 6,000 POUNDS OR MORE; AND RULES GOVERNING PERSONS ON BOARD SUCH AIRCRAFT
Subpart E—Special Airworthiness Requirements

§ 125.163 Fire-extinguishing agents.

Only methyl bromide, carbon dioxide, or another agent that has been shown to provide equivalent extinguishing action may be used as a fire-extinguishing agent. If methyl bromide or any other toxic extinguishing agent is used, provisions must be made to prevent harmful concentrations of fluid or fluid vapors from entering any personnel compartment either because of leakage during normal operation of the airplane or because of discharging the fire extinguisher on the ground or in flight when there is a defect in the extinguishing system. If a methyl bromide system is used, the containers must be charged with dry agent and sealed by the fire-extinguisher manufacturer or some other person using satisfactory recharging equipment. If carbon dioxide is used, it must not be possible to discharge enough gas into the personnel compartments to create a danger of suffocating the occupants.

JAR-OPS 1 - Commercial Air Transportation (Aeroplanes)

JAR-OPS 1.790 Hand fire extinguishers
(See AMC OPS 1.790)

An operator shall not operate an aeroplane unless hand fire extinguishers are provided for use in crew, passenger and, as applicable, cargo compartments and galleys in accordance with the following:
(a) The type and quantity of extinguishing agent must be suitable for the kinds of fires likely to occur in the compartment where the extinguisher is intended to be used and, for personnel compartments, must minimise the hazard of toxic gas
concentration;
(b) At least one hand fire extinguisher, containing Halon 1211 (bromochlorodifluoromethane, $CBrClF_2$), or equivalent as the extinguishing agent, must be conveniently located on the flight deck for use by the flight crew;
(c) At least one hand fire extinguisher must be located in, or readily accessible for use in, each galley not located on the main passenger deck;
(d) At least one readily accessible hand fire extinguisher must be available for use in each Class A or Class B cargo or baggage compartment and in each Class E cargo compartment that is accessible to crew members in flight; and

(e) At least the following number of hand fire extinguishers must be conveniently located in the passenger compartment(s):

Maximum approved passenger seating configuration	Number of Extinguishers
7 to 30	1
31 to 60	2
61 to 200	3
201 to 300	4
301 to 400	5
401 to 500	6
501 to 600	7
601 or more	8

When two or more extinguishers are required, they must be evenly distributed in the passenger compartment.
(f) At least one of the required fire extinguishers located in the passenger compartment of an aeroplane with a maximum approved passenger seating configuration of at least 31, and not more than 60, and at least two of the fire extinguishers
located in the passenger compartment of an aeroplane with a maximum approved passenger seating configuration of 61 or more must contain Halon 1211 (bromochlorodi-fluoromethane, $CBrClF_2$), or equivalent as the extinguishing agent.

ETOPS Requires Additional Fire Protection

On extended range twin-engine operations (ETOPS) flights (JAR - OPS 1.245) a cargo smoke detection and extinguishing system is required (see: **Ebel 1999**).

5.4 Flight/ Cabin Crew Rest Compartments (FCRC/ CCRC)

Langstreckenflugzeuge, wie z. B. der Airbus A330, A340 und A380 mit Reichweiten von bis zu 14000 Kilometern, werden aufgrund der Flugdauer und der damit verbundenen Arbeitsbelastung für Piloten und Kabinencrew mit einer zweiten Crew vorgesehen. Um ihnen eine möglichst ungestörte Ruhepause zu ermöglichen, werden in Langstreckenflugzeugenflugzeugen sogenannte Crew Rest Compartments eingebaut. Es sind nach einer Airbus-internen Vorschrift sind mindestens für die Hälfte der Besatzung Schlaf- und Ruheräume, auf Langstreckenflügen vorzusehen. Diese Compartments befinden sich an den Stellen in der Flugzeugkabine, wo keine Sitze bzw. wenige Sitzplätze verdrängt werden. Direkt hinter dem Cockpit befinden sind die

Ruheräume der Piloten, in der Größenordnung der A380 FCRC. Im Falle eines Notfalles wären die Piloten somit in Cockpitnähe. Ein FCRC ist für eine zweite mitgeführte Cockpitcrew vorgesehen. Sie umfasst im allgemeinen 2 Ruheplätze für Pilot und Co- Pilot. Ein CCRC ist für die Kabinenbesatzung vorgesehen und hat je nach betreibender Fluggesellschaft unterschiedliche Kapazitäten.

Layout principles for crew rest compartments (CRC) are defined in **SAE ARP 4101/3**. According to this specification, a *smoke detector* shall be provided in a CRC. Additional items of emergency equipment will be required if not immediately available in close proximity to the crew rest facility. These required items could be

- smoke hood
- protective breathing equipment
- BCF extinguisher
- fire gloves

5.5 Tank Inerting

Tank inerting or tank flammability reduction are methods to prevent fuel tank explosions. Flight International reports in the Boeing 737 flammability reduction system (FRS) in its December 6-12 issue:

HEADLINES

AIR TRANSPORT GUY NORRIS / LOS ANGELES

Inert tank debuts in airline service

Boeing poised to deliver first 737 with flammability reduction system to comply with proposed FAA regulations

Boeing expects to deliver the first 737-700 equipped with a fuel tank flammability reduction system (FRS) on 13 December and was completing flight-certification tests on the first aircraft late last week.

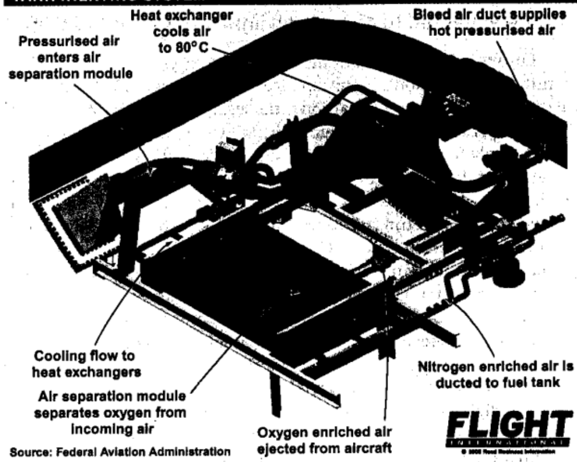
The work follows the recent start of a six-month in-service evaluation of the first FRS-equipped 747-400, and comes on the heels of a notice of proposed rule making (NPRM) issued on 14 November by the US Federal Aviation Administration calling for a fuel-tank inerting system to be installed on all US-registered airliners by 2012. Boeing, which also plans to deliver the second FRS-equipped 737 and 747 to customers over the next few days, says the effort is part of a campaign to field inerting systems for all its commercial models between 2006 and 2008.

The developments follow the 1996 crash of a TWA 747, which was determined to have been caused by a centre fuel tank explosion, and by the destruction on the ground of two 737s due to fuel tank explosions in 1990 and 2001.

In place of the heavy and expensive dedicated inerting systems first proposed to counter the flammability risk of partially empty fuel tanks, the FRS uses bleed air ducted to air separation modules that remove around 50% of the oxygen. The bleed air is then mixed with air from a nitrogen generating system to feed the fuel tank with virtually inert, nitrogen rich air.

Following earlier tests in 2002, the FAA determined that an oxygen level of 12% is sufficient to prevent ignition, rather than the 10% previously assumed. This was a key breakthrough as it virtually halved the size of the required inerting system, making it commercially viable. Boeing says the 12% level is achievable with one FRS air separation module on the 737, but that the 757/767 will require up to four, the 747 five and the 777 six. Although only one is required for all phases of flight on the 737, the much larger tanks

TANK INERTING SYSTEM



Source: Federal Aviation Administration

FLIGHT INTERNATIONAL

and fuel system of the 747 requires the use of one module for climb and cruise, and all five in descent when the flammability risk is highest. The 787 is the first Boeing aircraft to be designed with an in-built fuel-tank inerting system from the outset and will therefore not require modification to meet the forthcoming ruling. Boeing flight tested a prototype FRS system developed by Honeywell and Parker Aerospace on a 747-400 in mid-2003, and flight tested a scaled-down version on a Next Generation 737 in 2004.

References

Ebel 1999 EBEL, Stefan: Extended Range Operations with Two-Engined Aeroplanes. Fachhochschule Hamburg, Fachbereich Fahrzeugtechnik, Theoretische Arbeit, 1999. – Available from: http://bibliothek.ProfScholz.de

Ruff 1989 RUFF, Siegfried; RUCK, Martin, SEDLMYR, Gerhard: *Sicherheit und Rettung in der Luftfahrt*. Koblenz : Bernard & Graefe, 1989

Scholz 2002 SCHOLZ, Dieter: Standards als Mittel zur unternehmensübergreifenden Zusammenarbeit in der Luftfahrt-Industrie : Dokumentation nach ATA iSpec 2200. In: SCHOLZ, Dieter (Ed.): *Fit für die ATA iSpec 2200* (Forum: Fit für die ATA iSpec 2200 – Technische Dokumentation in der Luftfahrt-Industrie, TANNER AG, Lindau, 30. April 2002). Bonn : Deutsche Gesellschaft für Luft- und Raumfahrt, 2002. - DGLR-Bericht 2002-01, ISBN: 3-932182-25-1 – Available from: https://www.fzt.haw-hamburg.de/pers/Scholz/paper/TannerPaper.pdf

Bibliography to "Introduction to Aircraft Systems"

Aircraft Systems General

Moir 2001 MOIR, Ian; SEABRIDGE, Allan: *Aircraft Systems : Mechanical, Electrical, and Avionics Subsystems Integration*. Washington D.C. : AIAA, 2001 (AIAA Education Series)

BUNDESMINISTER FÜR VERKEHR / LUFTFAHRT-BUNDESAMT (Hrsg.): Grundlagen der Luftfahrzeugtechnik in Theorie und Praxis. Bd. II: Flugwerk. Köln : TÜV Rheinland, 1980

CUNDY, Dale R.; BROWN, Rick S.: *Introduction to Avionics*. Upper Saddle River, NJ : Prentice Hall, 1997

FEDERAL AVIATION ADMINISTRATION, DEPARTMENT OF TRANSPORTATION: Airframe and Powerplant Mechanics Airframe Handbook. FAA, 1976 (AC 65-15A). – 609 pages, available online from http://www.faa.gov

KINNISON, Harry A.: *Aviation Maintenance Management*. New York : McGraw-Hill, 2004

KROES, Michael J.; WATKINS, William A.; DELP, Frank: *Aircraft Maintenance and Repair*. Singapore : McGraw-Hill, 1993

LOMBARDO, David: *Advanced Aircraft Systems*. New York : TAB Books, McGraw-Hill, 1993

MIDDLETON, Donald H. (Ed.): *Avionic Systems*. Harlow, GB : Longmann, 1989

ROSKAM, Jan: *Airplane Design*. Vol. 4 : *Layout Design of Landing Gear and Systems*. Ottawa, KA : Roskam Aviation and Engineering Corporation, 1989. – Available from DARcorporation (http://www.darcorp.com)

WILD, Thomas W.: *Transport Category Aircraft Systems*. Casper, WY : IAP, 1990

WILKINSON, Ray: *Aircraft Structures and Systems*. Harlow, GB : Addison Wesley Longman, 1996

Definitions and Breakdown

AGARD 1980 AGARD: *Multilingual Aeronautical Dictionary*. Neuilly sur Seine, F : Advisory Group for Aerospace Research and Development, 1980. – Available online from NATO's Research & Technology Organisation http://www.rta.nato.int

AIR 171 SAE: Glossary of Technical and Physiological Terms Related to Aerospace Oxygen Systems. Warrendale, PA : Society of Automotive Engineers, 2000 (AIR171D). – Available from SAE (http://www.sae.org)

SAE: Aerospace Landing Gear Systems Terminology. Warrendale, PA : Society of Automotive Engineers, 1994 (AIR 1489)

SAE: Nomenclature, Aircraft Air Conditioning Equipment. Warrendale, PA : Society of Automotive Engineers, 1978 (ARP147C). – Available from SAE (http://www.sae.org)

	SAE: Terminology and Definitions for Aerospace Fluid Power, Actuation, and Control Technologies. Warrendale, PA : Society of Automotive Engineers, 1994 (ARP 4386)
ATA 100	AIR TRANSPORT ASSOCIATION OF AMERICA: Manufacturers' Technical Data (ATA Spec 100). Washington : ATA, 1999. – Available from ATA (http://www.airlines.org)
ATA 2200	AIR TRANSPORT ASSOCIATION OF AMERICA: Information Standards for Aviation Maintenance (ATA iSpec 2200). Washington : ATA, 2001
ICAO Annex 1	ICAO: Convention on International Civil Aviation, Annex 1: Personnel Licensing. 9th Ed. Montreal : International Civil Aviation Organization, 2001. – Available from ICAO (http://www.icao.int)
ICAO Annex 2	ICAO: Convention on International Civil Aviation, Annex 1: Rules of the Air. 9th Ed. Montreal : International Civil Aviation Organization, 1990
SAE 1998	TOMSIC, Joal L. (Ed.): *SAE Dictionary of Aerospace Engineering*. Warrendale, PA : Society of Automotive Engineers, 1998
WATOG	AIR TRANSPORT ASSOCIATION OF AMERICA: Airline Industry Standard, World Airlines Technical Operations Glossary (WATOG). Washington : ATA, 1992. – Available from ATA (http://www.airlines.org)

Certification

AC 25-17	FEDERAL AVIATION ADMINISTRATION, DEPARTMENT OF TRANSPORTATION: Transport Airplane Cabin Interiors Crashworthiness Handbook, 1991 (AC 25-17). – Available online from http://www.faa.gov
AC 25-22	FEDERAL AVIATION ADMINISTRATION, DEPARTMENT OF TRANSPORTATION: Certification of Transport Airplane Mechanical Systems, 2000 (AC 25-22)
ACJ-25	JOINT AVIATION AUTHORITIES: Joint Aviation Requirements for Large Aeroplanes (JAR-25), Section 2, Acceptable Means of Compliance and Interpretations (ACJ). – Available from the JAA (see: http://www.jaa.nl)
AMJ-25	JOINT AVIATION AUTHORITIES: Joint Aviation Requirements for Large Aeroplanes (JAR-25), Section 3, Advisory Material Joint (AMJ). – Available from the JAA (see: http://www.jaa.nl)

CS-25 European Aviation Safety Agency: Certification Specifications For Large Aeroplanes (CS-25). – Available online from http://www.easa.eu.int/home/certspecs_en.html

JAR-1 JOINT AVIATION AUTHORITIES: Definitions and Abbreviations (JAR-1). – Available from the JAA (see: http://www.jaa.nl)

JAR-25 JOINT AVIATION AUTHORITIES: Joint Aviation Requirements for Large Aeroplanes (JAR-25), Section 1, Requirements. – Available online from http://www.jaa.nl

FAR Part 25 FEDERAL AVIATION ADMINISTRATION, DEPARTMENT OF TRANSPORTATION: Part 25 – Airworthiness Standards: Transport Category Airplanes. – Available online from http://www.faa.gov

FEDERAL AVIATION ADMINISTRATION, DEPARTMENT OF TRANSPORTATION: Advisory Circular Checklist. FAA, 2000 (AC 00-2.13)

Safety and Reliability

Davidson 1988 DAVIDSON, John: *The Reliability of Mechanical Systems*. London : Mechanical Engineering Publications, 1988

MIL-HDBK-217 ROME AIR DEVELPMENT CENTER: Reliability Prediction for Electronic Systems. 1985 (ADA 163900). – Available from the National Technical Information Service (http://www.ntis.gov)

MIL-STD-1629 DEPARTMENT OF DEFENSE: Procedures for Performing a Failure Mode, Effects and Criticality Analysis. 1980 (MIL-STD-1629A). – Available from the National Technical Information Service (http://www.ntis.gov)

O'Connor 1991 O'CONNOR, Patrick D.T.: *Practical Reliability Engineering*. Chichester : John Wiley, 1991

Rome 1985 ROME AIR DEVELPMENT CENTER; HUGHES AIRCRAFT COMPANY: Nonelectronic Reliability Notebook, Revision B. 1985 (ADA 163900). – Available from the National Technical Information Service (http://www.ntis.gov)

RTCA/DO-160D RADIO TECHNICAL COMMISSION FOR AERONAUTICS: Environmental Conditions and Test Procedures for Airborne Equipment. Washington :

RTCA, 2001 (RTCA/DO-160D Change 2). – RTCA, Inc., 1140 Connecticut Avenue, N. W., Suite 1020, Washington, D. C. 20036 (http://www.rtca.org). Document also available from the National Technical Information Service (http://www.ntis.gov)

RTCA/DO-178B RADIO TECHNICAL COMMISSION FOR AERONAUTICS: Software Considerations in Airborne Systems and Equipment Certification. Washington : RTCA, 1992 (RTCA/DO-178B)

FEDERAL AVIATION ADMINISTRATION, DEPARTMENT OF TRANSPORTATION: System Design and Analysis. FAA, 1988 (AC 25.1309-1A). – Available online from http://www.faa.gov

Mass

BOEING, Weight Research Group: Weight Prediction Manual – Class I. Renton, WA : The Boeing Company, Commercial Airplane Division, 1968 (D6-23201 TN)

MIL-STD-1374 DEPARTMENT OF DEFENSE: Weight and Balance Data Reporting Forms for Aircraft. 1997 (MIL-STD-1374A). – Available online from http://www.sawe.org

Raymer 1992 RAYMER, Daniel P.: *Aircraft Design: A Conceptual Approach*. Washington D.C. : AIAA, 1992 (AIAA Education Series)

Roskam 1989 ROSKAM, Jan: *Airplane Design*. Vol. 5 : *Component Weight Estimation*. Ottawa, KA : Roskam Aviation and Engineering Corporation, 1989. – Available from DARcorporation (http://www.darcorp.com)

Torenbeek 1988 TORENBEEK, Egbert: *Synthesis of Subsonic Airplane Design*. Delft : Delft University Press, 1988

SAWE 2002 http://www.sawe.org (2002-02-28)

Power

SAE: Aerospace Auxiliary Power Sources. Warrendale, PA : Society of Automotive Engineers, 1995 (AIR 744B)

SAE: Power Sources for Fluidic Controls. Warrendale, PA : Society of Automotive Engineers, 1995 (AIR 1244A)

Costs and Trade-Off Studies

Shustrov 1999 SHUSTROV, Yury M.: "Starting mass" – a Complex Criterion of Quality for Aircraft On-board Systems. In: *Aircraft Design*, 1 (1998), p 193 - 203. – See: http://www.elsevier.com

Scholz 1998 SCHOLZ, Dieter: DOCsys - A Method to Evaluate Aircraft Systems. In: SCHMITT, D. (Ed.): *Bewertung von Flugzeugen (Workshop: DGLR Fachausschuß S2 - Luftfahrtsysteme, München, 26./27. October 1998)*. Bonn : Deutsche Gesellschaft für Luft- und Raumfahrt, 1998. – Available online from http://www.ProfScholz.de