



AEROSPACE INFORMATION REPORT

AIR1076™**REV. A**

Issued 1963-01
Reissued 1970-05
Stabilized 2025-10

Superseding AIR1076

Aircraft Fire Protection for Reciprocating and Gas Turbine Engine Installations

RATIONALE

This document is being stabilized for historical purposes to document aircraft fire protection practices of the 1960s and 1970s era.

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PREFACE

This document was issued in 1963 by the Powerplant Installation Committee of the Aerospace Industries Association (A.I.A.) as a design manual for all types of aircraft. Since then the originating Committee was dissolved and the manual became unavailable. In this period, advancements in aircraft fire protection methods have been produced by both governmental and private agencies that are not reflected in the manual. Recognizing this, but nevertheless feeling that there is much of present-day value in the manual, the SAE S-12 Helicopter Powerplant Committee believes it is performing a useful service to the helicopter industry in again making it available. Hence, the Committee herewith reissues without change, as an AIR, the entire original manual except for deletion of Acknowledgements. A future revision to this AIR to bring it up to date and to emphasize helicopter powerplant fire protection is under consideration by the S-12 Committee.

PURPOSE

The Aerospace Industries Association has published this design manual, containing fire-prevention information accumulated on civil and military aircraft, as a service to all organizations, government agencies, and individuals interested in aviation as well as to the aircraft designer, at whom the information is specifically directed. This material has been presented in concise indexed form to serve as generalized reference material and to provide background data for the designer. It is not intended that this be considered as proposed regulatory or specification material because it borders on maximum rather than minimum required airworthiness.

The Manual was first published 1 August 1949. It was previously revised on 15 April 1954 and 1 December 1957 and, in that time, has been used widely as a guide by many government and civil organizations of both domestic and foreign countries in the manufacturing, operating, and educational fields of aircraft.

SCOPE

This document is reissued for application to helicopters.

INTRODUCTION

The work done in the initial stages of design will de-

termine the final degree of fire protection inherent in a new helicopter; therefore, considerable foresight as to the eventual installation details is necessary. A lack of perception as to the relationship between a source of ignition and combustible fluids or materials may result in a combination which no amount of subsequent detailed design struggling can ever completely remedy. The inevitable design conflicts which arise on any new helicopter and the resultant compromises, should always consider the fire potential in order to obtain a sensible balance. For this reason, emphasis to keep the thought of fire protection prominent in preliminary design work is well worth the effort.

The following design points are intended to give a number of general rules for the fire protection features of preliminary design. If fire protection is considered in the preliminary design, the work of the detail designer trying to protect any particular section of the helicopter from the hazards of fire can be greatly simplified. Each helicopter is an individual problem and it is realized that many factors will affect the decisions in its design. However, the nearer the design can be to basic safety principles, the less will be the chance of trouble caused by detail design errors, maintenance in the field, or failures of equipment.

It is strongly felt that the basic safety responsibility for a helicopter lies on the drawing board. Each engineer concerned with the design of a system or component should realize its potential relation to all other affiliated and adjacent items and to the helicopter as a whole. Because the most important phase of fire protection is the prevention of occurrence of fire, each engineer responsible for the design of a component of a helicopter can contribute most satisfactorily to the basic safety of the helicopter if he has a thorough knowledge of the aircraft fire protection problem. Therefore, this Aerospace Information Report is built around a general discussion of fire protection. Mention of specific systems is made only where the general discussion does not apply, or where exceptions to the general discussion must be pointed out.

Regardless of the original fire protection design features built into the helicopter, it is necessary to maintain the helicopter properly to avoid increasing fire hazards; various means and procedures for accomplishing this can also be found in this AIR.

For purposes of discussion, fire protection consists of five basic divisions:

- Prevention of Occurrence of Fire
- Prevention of Spread of Fire
- Fire Detection
- Fire Extinguishment
- Ventilation and Smoke Evacuation

1. FIRE PROTECTION FOR RECIPROCATING ENGINE INSTALLATIONS

1.1 Fire Terms and Zone Definitions

1.11 Terms - Terms which must be defined to clarify their usage herein are the following:

1.111 Fireproof: A material which will withstand heat as well as or better than steel which will withstand 2000 F for 15 minutes and still fulfill its design purpose. When applied to materials and parts used to confine fires within designated fire zones, "fireproof" means that the material or part will perform this function under the most severe conditions of fire, and duration of fire, likely to occur in such zones. An example: Nacelle firewall, which resists 2000 F flame for 15 min.

1.112 Fire Resistant: When applied to sheet or structural members, "fire resistant" describes a material which will withstand heat as well as or better than aluminum alloy in dimensions appropriate for the purpose for which it is used. When applied to fluid-carrying lines, other flammable fluid system components, wiring, air ducts, fittings and power plant controls, fire resistant refers to a line and fitting assembly, component, wiring, duct, or controls which will perform the intended functions under the heat and other conditions likely to occur at the particular location. An example: Fire resistant hose which will resist 2000 F flame for 5 min.

1.113 Flame Resistant: Materials which will not support combustion to the point of propagating a flame beyond safe limits after removal of the ignition source. A test procedure to determine the minimum safe limits is presented in CAA Safety Regulation Release No. 259 dated August 25, 1947 (Reference 6).

1.114 Flash Resistant: Materials which will not burn violently when ignited.

1.115 Flammable: Solids, fluids, or gases which will ignite readily or explode. Methods for determining the relative flammabilities of fluids are being developed. A per cent nonflammable method applicable to fluids (aviation gasoline, kerosene, standard hydraulic fluid, lubricating oils, etc.) that are miscible with hexachlorobutadiene is presented in CAA Technical Development Report No. 142. - Determination of Ignition Characteristics of Hydraulic Fluids Part II Flammability Reference

Scale. May 1951 (Reference 8).

1.116 Compartmentation: The process of isolating components from other items with which they would normally be hazardous in combination.

1.117 Ventilation Stop: An isolating bulkhead, at least fire resistant, which is substantially vapor and liquid tight, for the purpose of controlling ventilation and liquid paths.

1.12 Zones and Zone Classifications

1.121 Combustible Zone: An airplane compartment containing equipment from which leakage of combustible fluids or vapors is not abnormal. An example: fuel cell bay.

1.122 Ignition Zone: An airplane compartment containing equipment which is normally an ignition source. An example: Inverter compartment.

1.123 Possible Fire Zone: A region in which an ignition source, together with combustibles, combustible fluid line leakage, or combustible mixtures, may exist at some time during airplane operation. The possible ignition source or combustibles might be contained within the region, or might enter the region from an external location during an emergency. The following should be considered to determine their possible hazard:

A. Nacelle Zones: Reciprocating engine nacelles are normally referred to as divided into the following three zones from a geographical standpoint (these are nacelle zones, as distinguished from fire zones).

Zone 1: The section within the front of the engine nacelle ahead of the fire seal or inner cowl seal (engine power section).

Zone 2: The nacelle section between the fire seal and the firewall (the accessory section).

Zone 3: The section within the nacelle and behind the firewall (wheel well space or rear nacelle skate).

B. All baggage compartments

C. Auxiliary power plant installation sections

D. Combustion heater installation sections

E. Other regions equally hazardous from the standpoint of fire possibilities.

1.124 Fire Zone: A "possible fire zone" which has been recognized and treated as a region which requires fire detecting and/or fire extinguishing equipment and a high degree of inherent fire resistance.

1.125 Designated Fire Zone: The CAA has recognized certain regions as fire hazards, and has called them "designated fire zones". For non-military aircraft, the CAA has declared the zones listed below to be in this category:

- A. Engine power sections
- B. Engine accessory sections
- C. Sections where no isolation is provided between engine and accessory compartment
- D. Auxiliary power installations
- E. Fuel burning heater installations

1.2 Prevention of Occurrence of Fire

1.21 General Rules

1.211 Design

A. Compartmentation: Separate and isolate combustibles from sources of ignition. In defining the application of this rule, any single potential failure of any equipment item (such as a leak in a fuel line connection, or burning out an electric motor) should be considered as a realistic basis under which the isolation principle should be met.

B. Drainage: Prevent combustible mixtures and fluids from accumulating by providing adequate drain holes and/or drain lines in all compartments where combustibles are encountered. Care should be taken to assure drainage throughout the normal range of flight and ground attitudes.

C. Re-entry Seals: Drain lines should extend below the exterior surfaces when practical and be sealed at the surface to prevent a return of vapor and liquid flow into the compartment.

D. Drain Location: Drain lines should lead to low pressure skin areas, and should be sufficiently large to quickly discharge large quantities of fluid under conditions of serious fluid line leakage. Drain line discharge should not come in contact with fluid line leakage. Drain line discharge should not come in contact with exhaust gases under any conditions of airplane maneuvering. Drainage paths should be examined to determine that fluids are not carried into openings or compartments where ignition hazards exist.

E. Leakage: Fuel and oil tank locations, and sump and vent locations, should be analyzed with the point of view in mind that leakage will sometime occur, and fire must not result. If it is necessary to locate a fuel tank immediately behind a fire wall, a ventilated air space of at least 1 in. should be allowed between the tank and the fire wall. Drainage paths should be included to provide for clearance from exhaust. Re-entry of drained fluids should be avoided.

F. Component Location: Combustible fluids tend to collect in the bottoms of compartments, so it is

desirable to keep exhaust lines and other ignition sources as high within each compartment as practical.

G. Exhaust Location: Avoid, where possible, running the exhaust system through zones containing combustible fluid lines, such as the accessory section. Exhaust gases should be discharged clear of the nacelle surface, so that they do not pass over access doors, drain outlets, or other places where combustible fluids may be present.

H. Exhaust vs. Combustibles: In general, combustible fluid carrying lines should be located on the opposite side of the nacelle from the exhaust system and from electrical wiring.

I. Exhaust Leakage: Particular care should be exercised to prevent exhaust system leakage. Leakage points produce flame, which is a greater hazard from the standpoint of ignition than bare exhaust pipe. Special attention should be given to locking all nuts on disconnect flanges, etc. Failure to exhaust clamp bolts has been generally chronic. In some installations the use of double bolts has provided a desirable safety factor. Exhaust systems should be supported in a manner which will preclude displacement of a portion of the collector in the event of a bolt or nut failure. This avoids the condition where a large amount of exhaust impinges on shrouding, cowling, etc.

J. Exhaust Shrouds: Exhaust systems should be completely separated from the accessory section and Zone 3 by substantially vapor-tight fireproof shrouds. If the exhaust system passes through the lower part of Zone 2 or 3, it may be desirable to use a double shroud with ventilating air flowing between the inner and outer shroud. The temperature of the accessory section surface of the shroud should be kept below 500 F, for all operating conditions.

K. Fuel Vent Configuration: Fuel vent systems must be designed so that fluids will not spill out during maneuvering. Actual ground tests should be conducted under conditions of maximum acceleration, deceleration, and 360 deg turns on a sharp radius. Flight test and analysis should include consideration of maximum roll, climb and glide angle, and yaw.

L. Fuel Vent Outlets: Fuel vent outlets should be so located and designed that solid fuel exiting from them cannot impinge on any airplane surface. Malfunction or misuse of fuel transfer systems should not cause a high rate of fuel flow to be pumped out the vent.

M. Fuel Dump System: Fuel dumping systems must be designed so that fuel will not impinge on any airplane surface while being dumped. Ground

checks should be made frequently, to prove that lines are intact, and will not leak in the event they are used in flight. The fuel dump system should be designed so that it depends upon neither the electrical nor the hydraulic system for proper function.

N. Wiring Location: Wiring should be installed well above combustible fluid lines, where the presence of both items is necessary. Frequent supports are necessary to prevent a free end of a broken wire from touching fluid lines or tanks.

O. Electrical Equipment: Electrical system equipment should be examined critically for possible sources of ignition both under normal as well as on the ground operation and possible conditions of failure. In any zone such as a fuel tank where combustible fluid or vapor may occur in normal operation, any such equipment which might be an ignition source under normal operation or possible conditions of failure, should be contained within an explosion proof casing as defined by Procedure II in specification MIL-E-5272A. In any zone where combustible fluid or vapor may occur only as a result of abnormal conditions such as leakage of a fuel line, equipment which might be an ignition source in normal operation should be contained within an explosion proof casing or enclosed within a vapor-safe compartment. Resistors, shunts and other high-temperature electrical equipment should be examined carefully for possible fire hazards when operating at their maximum temperature conditions.

P. Plumbing expansion: Bends or other expansion means should be incorporated in all tube runs to avoid rupture of tubing.

Q. Plumbing support: Adequate support of fluid lines is essential to eliminate breakage due to vibration. Particular attention should be given to the spacing of supports to dampen resonant vibration frequencies. The practice of supporting tubes from each other should be avoided. The practice introduces the possibility of fatigue failure because of the differences in vibration and expansion.

R. Plumbing Motion: Where flexible lines are used, ample slack should be provided where relative motion occurs between components.

S. Plumbing Bends: Below standard radii should be avoided on tubing to eliminate possible fatigue failure at bends.

T. Plumbing Connections: All combustible fluid lines should incorporate the most dependable type of connections available to prevent leakage. Nipples and hose clamps are not satisfactory where any possibility of appreciable vibration, relative motion, or axial loading exists.

1.212 Materials

A. Grommets: The use of flexible grommets as supports through bulkheads should be avoided to eliminate vibration fatigue and cutting of lines.

B. Hose: Hoses used should have an exterior surface suitable to resist all types of fluids used on the airplane so the hose will not deteriorate when exposed to any of the fluids.

C. Flexible vs. Rigid Lines: In any installation where relative motion between line support points can exist due to vibration or structural working, flexible lines should be used in place of solid lines of 1/4 in. diameter or smaller. Small lines have a tendency to fail due to vibration and maintenance damage.

D. Insulating Conduit: Tubing of Nylon, Teflon, or the equivalent should be used over open wiring installations where combustible fluids may contact the wires, or where chafing of the wires could occur.

E. Hose Clamps: If hose clamps are used, the recommended torque should not be exceeded. Excessive torque causes premature failure of hose material.

F. Wire Material: Aluminum electrical wiring should not be used on any critical components anywhere in a fire zone, nor where it must be connected to shock mounted equipment or equipment subject to frequent replacement.

1.22 Cabin Interior, Baggage and Cargo Compartments - Fire Prevention

1.221 In addition to the general rules above, the following special features must be considered under this heading:

A. Fabrics: All materials used for upholstery, floor covering and decorations should be at least flame resistant. It should be realized that most materials lose their flame resistance at high ambient temperatures.

B. Stowage: Provisions should be made for stowage of blankets, pillows, etc., in places where they will not be ignited by light bulbs, matches, cigarette ashes, etc.

C. Ash Trays: Adequate numbers of fireproof, self-containing, removable ash receptacles should be provided.

D. General Hazards: Wiring and combustible fluid lines should be kept to a minimum, and should be inspected frequently for damage or leakage. In critical locations combustible fluid line fittings should be shrouded with nylon, teflon or the equivalent or other similar clear material, and drained overboard. Where wiring cannot be excluded from baggage or cargo compartments, the wiring should be protected by duct of fiberglass

impregnated with a suitable fire resistant and non-afterglow resin. Such covering is rugged, easily worked and molded, and also is a non-conductor.

1.23 Specific Measures

1.231 Compartment Pressure Test: After the compartmentation of 1.211 (A) is established, design and test to assure that combustible zones run at lower pressure than any adjacent ignition zones.

1.232 Drainage Test (Internal): Make a physical drainage check of the airplane through its range of stabilized (not transient) attitudes using realistic average leakage rates for each possible hazard. If horizontal surfaces or minimum drainage paths are involved, the combustible fluid expected should be used to duplicate the surface tension effects, if practical.

1.233 Drainage Test (Overboard): All overboard drains and vents from which a substantial rate of drainage is possible should be dye-checked in flight to assure safety from the standpoint of re-entry or external ignition by exhausts.

1.3 Prevention of Spread of Fire

1.31 General

1.311 Design Features

A. Isolation: All fire zones should be completely separated, one from the other, and from other parts of the structure by firewalls or by tight fitting ventilation stops if the hazard is considered minor. It must be assumed that such items as fuel lines, booster pumps, etc., may fail at some time, and possibly start a fire. Separate compartments within the wing or fuselage will help to isolate such fire sufficiently to allow for all possible counter-measures to be tried.

B. Ventilation: To avoid the spread of flame and smoke to the fuselage, any necessary ventilation flows should be so arranged that fire cannot travel inward through the wing from fire zones. Also, the design should be arranged so as to prevent fire following ventilation paths from one fire zone to another, such as from an outboard engine to an inboard engine. Ventilation stops are ample for most points within the wing.

C. Airscoops: All airscops must be located in a manner such that fire from other parts of the airplane cannot enter them. Serious fires have occurred where flames have ignited oil in carburetor airscops and in fire damaged oil coolers.

D. Ducting: Ventilation ducts and generator blast tubes must in some cases pass through or terminate in fire zones, and their failure during a fire might cause the introduction of air in large quantities. These ducts should be fireproof where they pass through fire zones. When they terminate in fire zones, they should be provided with shutoff valves, or sufficient extinguishing agent should be dis-

charged into them so that the mixture flowing through the ducts will not support combustion.

E. Shutoff Valves: Combustible fluid supply lines which pass through the engine firewall should incorporate shutoff valves located outside any fire zones, unless fireproof valves and controls are used.

F. Fittings: Lightweight flange fittings using brazed or silver-soldered construction offer questionable fire resistance unless used in a system with a continuous flow of low vapor pressure fluid during fire conditions. "Sandwich type" flange-bulk-head-flange installation should not be used. Aluminum fittings of the AN type are acceptable in fire zones in lines of 1 in. tube diameter and larger.

1.312 Materials

A. Absorbent Materials: The use of unprotected, absorbent materials as asbestos, fiberglass, or metal "wool", which will absorb flammables and be difficult to extinguish, should be avoided. Also materials such as phenolics which will smolder or glow and constitute a possible source of re-ignition of fire should be avoided.

B. Flame Resistance: Where possible, materials which are flame resistant or better should be used.

C. Insulation: Flame resistant non-absorbent insulation or better should be used on all wiring.

D. Fireproof Wiring: Wiring to vital emergency equipment, such as the propeller feathering circuit, shutoff valves, magneto ground-wire, etc., should be as fireproof as possible, particularly in fire zones. Good results have been obtained by enclosing each strand of a fire resistant wire in asbestos, then inserting the group of wires into a snug fitting stainless steel conduit. With this arrangement, even though the original insulation is burned, the asbestos serves to provide reasonably good insulation following a fire. If, however, a stainless steel conduit is employed, care must be taken to prevent the entrance or entrapment of moisture and/or other foreign matter in low impedance circuits such as bridge circuits. Where it is impractical to seal the conduit, ceramic rather than asbestos may be considered as an insulator.

E. Tubing: In designated fire zones, rigid tubing which carries combustible fluids or vapors should be of fireproof material.

F. Flex: Flexible hose and fittings in fire zones should be fire resistant.

G. Fireproof Flex: Flexible hose required as functional parts of vital emergency equipment such as propeller feathering lines should be as fireproof as possible. Good results have been obtained by using double wire braid hose with flame impingement protection for the end fittings.

H. Ducts: Ducts passing through firewalls should be kept to a minimum. When such ducts are necessary, care should be taken to use fireproof materials such that fire cannot by-pass the firewall by burning into or out of the duct.

I. Cowling: Cowling enclosing fire zones should be of fireproof material so that flame exit can occur at controlled locations only. Cowling, leading edges, etc., of adjacent hazardous areas downstream of these exits should be fireproofed to prevent burning back into these zones by flame from the above exits.

1.32 Purging

1.321 Internal Fuel Tank Purging: It is considered that reciprocating engine installations have low probability of inherent failures of the type that will penetrate fuel tanks with hot fragments. It is also felt that the typical location of the wing tanks behind the plane of the engine makes the only potential advantage of purging that of prevention of spread of fire. The exception is that of a turbosupercharger so located that fuel is tanked in the plane of the turbine, and, if protection from this is desired, the techniques are discussed in par. 2.24. Although internal fuel tank purging has proven effective in explosion prevention against incendiary gunfire and tank piercing fragments, it is considered to be ineffective in preventing tanked fuel fires resulting from an ignition source burning into the tank from outside. The reason is that the penetration wound in battle damage is sufficiently small that the inerted atmosphere within a tank is changed little during the few milliseconds that an incendiary, for example, presents an ignition source. Contrast this with the relatively steady-state conditions of burn-through of an average tank where a constant ignition source is present while the wound gradually burns large enough to dissipate the purge. It can be seen that the only gain will be in time; inerting will change little in the end result. Special conditions might exist in which explosion as the result of external fire is the major hazard. For example, a completely fireproof tank, normally empty, low R.V.P. or cold fuel. In such case, internal inerting might pay and should be considered. (See par. 2.241 for details)

1.322 Fuel Cell Bay Purging: The principle of providing an inert layer around the fuel tank may, like internal inerting, have advantage in special application but is generally ineffective for the same reason. The reason is that the condition wherein fire penetrates into the inert zone presents a high probability of losing the inert atmosphere.

1.323 Compartment Purging: Although continuous or intermittent flow purging system might readily be adapted for a fire prevention means for inaccessible aircraft compartments, such as the baggage compartment, the remote occurrence of fire originating within makes the value questionable.

Instead of a fire prevention system, an adequate fire extinguishing system is considered more practical. Consideration has been given to inerting high airflow zones such as engine compartments. It is noted that such a design is comparable in required flow rate and effect to a fire extinguisher system. Such inerting rates for steady state conditions would result in prohibitive weight.

1.33 Cabin, Baggage and Cargo Compartments:

In addition to the above mentioned measures for prevention of spread of fire, the following special items should be considered.

1.331 Waste: Waste materials must be stowed in closed, fire resistant containers.

1.332 Finishes: Cabin interior finish materials should be treated so that they will not smolder or glow excessively after flame is removed.

1.333 Fabrics: Fire resistant materials should be used throughout the interior of baggage and cargo compartments. It should be kept in mind that the materials should be selected so as to provide the greatest possible resistance to a general conflagration.

1.334 Toxicity: Material whose products of combustion are dangerously toxic should be avoided.

1.4 Fire Detection

1.41 General - Wherever a fire zone is indicated by design analysis, a means of detection of a hazardous condition should be employed. The type of detection and the presentation or use of its warning should be carefully suited to the type of hazard and the emergency procedure to combat it.

1.411 There are three general types of detector-procedure systems now in use:

A. Manual: This type of system utilizes warning lights to alert the pilot who then follows prescribed cockpit procedure as a counter-measure. Such a manual system is adequate for hazards in which a few seconds are not important. For example, a baggage compartment system or one for an airplane with a very simple cockpit should probably be chosen as manual.

B. Semi-Automatic: Occasionally an airplane becomes sufficiently complex that the emergency procedure exceeds reasonable expectations of the pilot. In such case, psychology must be weighed against complexity, and "panic switches" combining multiple procedure functions provided to simplify the mental demands on the pilot. It is noted that speed is gained by such design for such hazards as may need it.

C. Automatic: As the name implies, the detector of such a system automatically triggers the appropriate counter-measures and warns the pilot simultaneously. Such a system must be carefully weighed to assure that the advantage outweighs the weight and potential malfunction.

1.42 Types of Detectors

1.421 General: Fire, or dangerous fire conditions can be detected in any of seven different manners:

- A. Flame detectors
- B. Rate-of-Temperature-rise detectors
- C. Overheat detectors
- D. Smoke detectors
- E. CO detectors
- F. Combustible mixture detectors
- G. Observation of crew or passengers.

In many airplanes it is desirable to have a detection system which incorporates several of these different types of detectors. Flame detectors are most useful where the materials present will burn brightly soon after ignition, such as in the power plant accessory section. Rate of rise detectors are well suited to compartments of normally low ambient temperatures such that a fire produces a high temperature differential and rapid temperature rise. Overheat detectors should be used wherever the hazard is evidenced by temperatures exceeding a predicted, set value. Smoke detectors obviously are best suited to areas where materials may burn slowly, or smolder. Baggage compartments are in this category. In many cases one set of sampling equipment can be used to indicate dangerous concentrations of carbon monoxide in several different regions. Chemical sampling equipment in the form of a combustible mixture detector is very useful in protecting certain regions from trouble due to accumulations of explosive gases.

The three major detector types used for fast detection of fires are the flame, rate of rise, and overheat detectors. Flame detectors are basically "volume" type which senses flame within a visible space. Overheat fire detectors can be obtained in either "continuous" or "unit" type. Where an excessively large number of unit detectors would be required, the continuous type can often be installed, giving lower weight, simpler installation, reduced wiring complications, and lower initial cost. Pure rate of rise detectors are currently "unit" type only.

Basic specifications for fire detectors are included in Reference 9.

1.422 Features of Fire Detector Systems

- A. The system should:
 - (1) Indicate fire immediately after ignition, and show accurately the location of the fire.
 - (2) Remain on for duration of fire.
 - (3) Indicate when fire is out.
 - (4) Indicate re-ignition of fire.
- B. The system should not cause false warnings under any flight or ground operating condition.
- C. Facilities should be incorporated so that the system can be electrically tested from the cockpit in as representative a manner as practical.
- D. Detector units should be of rugged construction,

to resist maintenance handling, exposure to gasoline, oil, dirt, water, low temperatures, vibration, stale air, fungus, and altitude. Also, they should be light in weight, small, and compact, and readily adaptable to desired positions of mounting.

E. The detector system should operate on the airplane electric system without inverters. The circuit should require minimum current unless indicating a fire or unless a monitoring system is in use. A heat detector system should give an indication at a dangerously high temperature regardless of the rate of rise.

F. Fixed temperature detectors should be set at 100 to 150 F above maximum safe ambient temperature, or higher when in compartments where extremely high rate of rise is normally encountered.

G. Detector system components located within potential fire zones should be fireproof.

H. Smoke detectors should be sensitive to either light or dark colored smoke, and should not indicate fire in a dusty or foggy atmosphere, unless a fire exists.

I. Each detector system should actuate a light and/or an audible alarm which indicates the location of the fire.

J. Provision should be made to safeguard against possible interference of baggage or cargo with the operation of fire detectors.

K. For systems other than flame detector systems, the ventilation air through fire zones should always flow in one direction only, i.e., no reverse flow under any operating conditions. Stagnant air spaces should be reduced to a minimum. The number of ventilation air exits should be kept to a minimum. Compliance with these recommendations allows the effective placement of a minimum number of detectors.

L. Two or more engines should not be dependent upon any one detector circuit. The installation of common zone detection equipment prevents the detection system from distinguishing between the engine installations, necessitating shutting down both engines in the event of fire.

M. Basic specification for installation and testing of fire detecting systems are included in Reference 10.

1.43 Detector Locations

1.431 General

A. Each fire zone should be equipped with an adequate fire detection system, unless fire in that region would be readily discernible to crew or passengers. Each fire extinguisher system requires a separate detection system.

B. Detectors must be located so that all parts of the fire zones being considered are covered.

C. Detectors, with the exception of flame detectors, should be located at points where the ventilation air leaves compartments, so that temperature, mixture, and smoke indications can be obtained with a minimum number of units.

D. Flame detectors should be located such that any flame within the compartment is immediately sensed. This may or may not be where the ventilation air leaves the compartment.

1.432 Power Plant Detector Locations - Fire detectors should be installed in the following zones. The comments pertaining to detailed location apply for the current unit type heat detectors.

A. Power section (zone 1) - around periphery of diaphragm in cooling air stream at points of air egress, spaced at not over 18 in. (measured along the arc).

B. Accessory section (zone 2) - air outlets, hazardous areas, and near ignition sources such as exhaust shrouds, and in ventilation paths.

C. Induction system (in some installations) - downstream from blower, intake pipes, or diffuser section.

D. Zone 3 (aft of firewall) - in all air exits, stagnant air spaces, and near ignition sources.

E. Exhaust system shroud outlets in turbosupercharged installations where exhaust leakage is a problem.

1.433 Heater Protection

A. A fire detector should be placed in the hot air duct downstream of the heater.

B. If the heater fuel system or exhaust system configuration is such that it is a fire hazard, the compartment surrounding the heater should be examined as a possible fire zone.

1.5 Fixed Fire Extinguishing Systems

1.51 General Design Information - A fixed fire extinguisher system should dilute all the atmosphere within and entering a compartment with sufficient inert agent that it will not support combustion, and continue the process for a duration sufficient that existing flame is extinguished. Conventional systems utilize perforated tubing or discharge nozzles to distribute a specific quantity of agent in approximately two seconds. Recently developed HRD (high rate of discharge) systems utilize open end tubes to deliver a given quantity of agent within 1.35 seconds for CO₂ and 1 second for all other agents. CAA tests indicate that unrestricted release through such an open end tube distribution system can be relied on for adequate distribution when CO₂ or the more volatile liquid agents are used, provided the outlets are located properly. Although the discharge times given above are considered satisfactory, discharge times of 0.5 to 0.9 seconds have been obtained with existing equipment and it is believed that any reduction in discharge time below

that specified would improve system effectiveness.

1.511 General Rules of Design

A. An adequate fire extinguishing system should be installed in each fire zone region where other adequate means are not provided and which cannot be readily entered by a crew member with a portable fire extinguisher.

B. Agents should not be used which will be injurious to the primary structure of the airplane. It is desirable to use agents which will not be injurious to the contents of the compartment; however, effective fire extinguishment is the primary consideration.

C. Toxic agents should not be used in fuselage compartments or in other compartments where the agent could be transmitted in harmful quantities to habitable fuselage compartments by the ventilating system or by any other means. All known fire extinguisher agents including CO₂ are toxic to some extent.

D. Portions of the fire extinguisher system located in potential fire zones should be fireproof where the maintenance of a distribution system during a fire is critical, except discharge tubing in baggage compartments, which may be of dural.

E. The supply of agent or the valves controlling its flow should not be located in a fire zone.

F. The agent containers should be either "winterized" for extreme temperature operation or so located in the airplane that they will not be subjected to extreme temperatures. Safe limits for unwinterized carbon dioxide cylinders are approximately 0 to 140 F. Safe limits for "CB" and CH₃Br spheres are -65 to 200 F. The cartridge detonators used with these systems have a variable age-with-temperature limit, the present maximums being 720 hrs at 160 F. Tests being conducted at the Wright Air Development Center of the Air Force should yield much higher time limits at the elevated temperature. Contract should therefore be made with the manufacturer for the latest information available at the date of contemplation of the system.

G. The fire extinguisher system may be either electrically controlled or cable controlled. The control system, either cables or electric wiring preferably, should not pass through any fire zones. Any portion of the controls which must be located in fire zones should be fireproof. If the system is electrically controlled, care should be taken to make certain the power source is not affected by fire control procedures.

H. A two shot system, capable of handling the largest hazard with release of one shot, should be installed for application to engine compartments

on all multi-engine transport aircraft. Single shot systems are acceptable for baggage and cargo compartments, and for combustion heaters, etc. (Note: See formula par. 1.54)

I. Indicators should be installed in the system to show when the agent containers have been discharged, either because of an overheat condition, or accidental or intentional discharge of the system. These discharge indicators should be so located that they may be easily inspected.

J. When a compartment is to be flooded with agent and there is a source of fresh air entering the compartment, the incoming air should be either shut off prior to the release of the agent or rendered inert by directing extinguishing agent into the air blast (preferably the former).

K. Ground Nacelle Fires

1. With the increased size of airplanes, the problem of ground fires has become more and more serious. It is sometimes difficult to discharge a ground fire extinguisher effectively into the engine accessory section of a large airplane. For this reason, a central ground connection to the airplane distributing system may prove desirable as a part of the fire extinguisher system. In addition to making the ground fire extinguishing agent more effective, it eliminates the necessity of removing and recharging the airplane cylinders, which otherwise might have to be discharged. The ground connection should include means by which the entire system can be operated from one place, either the cockpit of the airplane or the location of the agent supply on the ground.

2. If the system in 1. above is not provided, it is necessary that ground fire fighting crews have ready access to Zone 2. This is best provided by incorporating a spring-loaded access door in the most desirable location in the skin of Zone 2. This door should be located in an accessible area, but not directly in the bottom of the nacelle, nor in any other

region where the opening of the door might spill burning liquids upon fire fighters. Such a door should provide 5-1/2 x 10 in. (Ref. 3) clear opening, which will allow the insertion of the horn of a 50 or 100 lb CO₂ extinguisher. No latch should be used to hold this door closed.

3. Most Zone 1 fires encountered on the ground can be blown out by accelerating the engine briefly to rated speed. If a single acceleration does not result in blowing out the fire, the engine should be shut down and the customary ground fire fighting measures should be taken.

L. Consideration should be given to the design of the power zone to keep it as clean aerodynamically as possible. When pockets of low air velocity are present, the fire may hang on at these points and be very difficult to blow out.

M. The volume of each potential fire zone should be kept to a minimum, giving due consideration to other problems such as accessibility of components for maintenance.

N. When built-in fire extinguisher systems are installed in baggage or cargo compartments, means should be provided to shut off ventilating air in case of fire. This will permit the extinguishing agent to be retained for a longer period of time, which is very important in the case of a smoldering fire. Compartment sealing and ventilation shut off should be so designed and maintained that at least a 25% concentration of agent is maintained after 1 hr for over land operation or 2 hrs for over water operation.

O. If an electrical system is used, it should be as simple and reliable as possible, and it should tie into the airplane electrical system in a manner such that other electrical failure will not affect the operation of the system. (See section 2.5 Fire Extinguishing Control Circuits in Ref. 13A, AIA Design Manual on Aircraft Electrical Installations.)

P. Current fire extinguisher installation and test specifications are included in Reference 11.

1.52 Fire Extinguishing Agents

Agents	Advantages	Disadvantages
Carbon Dioxide CO ₂	Safest agent to use from the standpoint of toxicity and corrosion hazards.	Mental confusion and suffocation hazard to occupants if sufficient gas is discharged into personnel compartments from baggage compartment. CO ₂ has an extremely large variation in vapor pressure with temperature which makes it necessary to use stronger (heavier) containers than are required for methyl bromide.

Methyl Bromide <chem>CH3Br</chem>	More effective pound for pound than <chem>CO2</chem>. Approx. 80% of this agent by weight as compared to <chem>CO2</chem> is required. Less variation in vapor pressure than <chem>CO2</chem>. Much lower container pressure required resulting in lighter containers. Treated magnesium alloys are satisfactory for use in <chem>CH3Br</chem> systems outside of the potential fire zones.	Much more toxic than <chem>CO2</chem>. Due to its toxic effect on humans, <chem>CH3Br</chem> should not be used as a fire extinguisher agent in areas where harmful time concentrations can enter personnel compartment. A warning agent such as colored smoke or a harmless irritant should be mixed with the agent. Aluminum alloy material should not be used in methyl bromide systems due to serious corrosion and possible spontaneous ignition. Rapidly corrodes aluminum, magnesium, and zinc. Tubing systems should be vented at all times and steps should be taken to free the tubing of residual methyl bromide after each discharge. Containers must be recharged at the extinguisher manufacturer's plant or at a depot by specially trained personnel.
Bromochloromethane ("CB") <chem>CH2BrCl</chem>	Less toxic than <chem>CO2</chem> in normal state. Non-corrosive to aluminum, magnesium, steel and brasses. One of the most effective agents available.	Toxic when pyrolyzed. High vapor pressure compound - 220 psi at 70 F.
Dibromodifluoromethane	One of the more effective agents available. Low vapor pressure compound - 14 psi at 70 F. Toxicity of unpyrolyzed agent about equal to unpyrolyzed <chem>CCL4</chem>. Non-corrosive to aluminum, steel and brasses.	Toxicity of pyrolyzed agent considerably worse than that of pyrolyfied <chem>CCL4</chem>.
Trifluorobromomethane <chem>CF3Br</chem>	Basically non-toxic in both pyrolyzed & normal states. Effectiveness similar to that of "CB".	High vapor pressure compound - 220 psi at 70 F. Current availability limited and will be expensive even in production.

Note: The relative effectiveness of the various agents listed above is considerably influenced by the type of system employed, HRD or conventional; by the method of distribution, open end outlet, nozzle, or spray ring, and by the air flow conditions. Review of the data contained in References 11 J & L before selecting the agent for a given application is advisable.

1.53 Fire Zone Classifications - For purposes of defining the type of hazardous zone from the standpoint of appropriate fire extinguishing technique, the following classifications are used:

Class A: Zones through which flow large quantities of air past regular arrangements of similarly shaped obstructions. The power section of an air cooled

engine will be classified in this group.

Class B: Zones through which the quantity of air flowing is large compared to the volume of the region. The air passages in these zones are also relatively clean aerodynamically speaking. Heat exchanger ducts, exhaust manifold shrouds and the like may be included in this category.

Class C: Zones through which the quantity of air flowing is relatively small compared to the volume of the region. An engine accessory compartment in a nacelle provided with a diaphragm separating the power section is an example of this type of zone.

Class D: Zones through which there is no air flow or an almost negligible air flow. This includes wing or fuselage compartments exemplified by

wheel well enclosures in which there is little ventilation provided. Baggage compartments, however, are considered separately from this class and discussed in paragraph 1.54.

1.54 Quantities of Agent Required

1.541 Production Airplanes

A. Conventional Systems (weight required in 2 sec.)

Zone Classification	Air Force Factors	BuAer Factors		C. A. A. Factors	
	CH ₂ BrCl CB (lbs)	CCO ₂ (lbs)	CH ₃ Br (lbs)	CO ₂ (lbs)	CH ₃ Br or GB (lbs)
A	.56 Wa+ .16 Vnet	0.70 Wa	.56 Wa+ .16 Vnet	0.70 Wa	0.56 Wa
B	.56 Wa+ .16 Vnet	0.50 Wa	.56 Wa+ .16 Vnet	0.50 Wa	0.40 Wa
C	.56 Wa+ .16 Vnet	0.14 V+ 0.70 Wa, or .20 V (Use greater)	.56 Wa+ .16 Vnet	0.20 V	0.16 Wa
D	.56 Wa+ .16 Vnet	0.14 V	.56 Wa+ .16 Vnet	0.14 V	0.11 Wa
Cargo Compartment				*0.11 V	

*The 0.11 V factor is acceptable to the CAA providing there is less than one air change per hr through the cargo compartment when loaded to maximum volume capacity.

Note: When liquid agents such as CF₂Br₂ or CF₃Br not listed in the above table are used, it is assumed that the formulas given for CH₂BrCl, CH₃Br, and "CB" can be safely applied.

B. High - Rate - Discharge Systems (weight required in 1.35 sec. for CO₂ and 1 sec. for all other agents). CAA recommendations for HRD systems are as follows for the time limits specified:

Agent	High Airflow Smooth Zone*	Low Airflow Smooth or Rough Zone	No Airflow Smooth or Rough Zone
CH ₃ Br	0.02V + 0.25 Wa	0.05V	0.02V
CBr ₂ F ₂	0.02V + 0.25 Wa	0.05V	0.02V
CBrF ₃	0.02V + 0.25 Wa	0.05V	0.02V
CH ₂ BrCl	0.025V + 0.4 Wa	0.06V	0.025V
CO ₂	0.03V + 0.5 Wa	0.07V	0.03V

*This does not apply to high airflow zones having uneven internal surfaces because of a "turbulence factor" the nature of which has not yet been determined. (In

certain tests conducted by the CAA, up to 3 times as much agent was required in "rough", high airflow zones as in identical zones having a smooth internal surface. (See References 11 G, I & J.)

Symbol Identification - Wa = Pounds of air (cruising conditions) per second flowing through zone. V = Gross volume of zone in cubic feet. Vnet = Gross volume of zone in cubic feet minus the volume of major items of equipment.

It is noted that the CAA CO₂ (former Air Force requirements) requirements were established from fire tests in a DC-3 nacelle. These requirements were based on the assumption that power sections from that day forward would have approximately the same proportion between gross volume and occupied space, hence the requirement per gross volume. Since this is not necessarily true in present design, the knowledge of this

basis is of value in evaluating the adequacy of an installation, particularly in the event of a limited agent supply.

1. 542 Discharge Time

A. Conventional Systems - All the agent weights defined by paragraph 1. 541A are standard minimum weight requirements which must be discharged within a 2 second time period. This, in effect, establishes a minimum rate and time for discharge. Occasionally, however, a complex system may be rate limited by its components at a value which will not supply the standard requirements for all compartments simultaneously.

In this event, the CAA and Navy have permitted decreasing the rate into low airflow compartments (Class C & D) such that the weight in paragraph 1. 541A is discharged in a time up to 6 seconds. Note, however, that Class A & B compartments must still be maintained at the standard rate for at least two seconds. Interpreting this in terms of a unit system design, it means that the weight of agent to Class A & B hazards will increase proportionally to the extension of time above 2 seconds but that the total system rate can be decreased.

Zone Classification	A	B	C	D
C. A. A.	required RATE 2 sec. Min.	required RATE 2 sec. Min.	required WEIGHT 2-6 sec.	required WEIGHT 2-6 sec.
Navy	required RATE 2 sec. Min.	required RATE 2 sec. Min.	required WEIGHT 2-6 sec.	required WEIGHT 2-6 sec.
Air Force	required RATE & WT 2 sec.	required RATE & WT 2 sec.	required RATE & WT 2 sec.	required RATE & WT 2 sec.

B. High - Rate - Discharge Systems: All of the agent weights defined by paragraph 1. 541B are minimum weight requirements which must be discharged within 1.35 sec. in the case of CO₂, and within 1 sec. for all other agents. However, discharge times of 0.5 to 0.9 sec. have been obtained with existing equipment and it is believed that any reduction in discharge time below that specified would improve system effectiveness.

1. 543 Experimental Factors - Because of higher fire probability and importance of highest reliability of the fire extinguishing system on initial experimental aircraft, the Navy and Air Force have increased requirements as follows:

First experimental aircraft should be equipped with a system such that the minimum quantity of agent per zone is 4 times that determined from standard requirements and the discharge duration is 4 sec. or less (i. e., twice the normal rate for twice the normal time).

1. 55 System Design

1. 551 General - The possible variety of tankage and plumbing configurations to accomplish the result should be examined for each specific aircraft in order to achieve the optimum. Systems can vary from tankage in a central location which is directed through complex distribution systems to various hazards to agent which is

tanked adjacent to each hazard. Terminology generally accepted to define various arrangements is as follows:

A. Central System: A single supply of agent, centrally located, with valves to direct the agent to any protected zone or zones.

B. Central Wing: A central supply of agent located in each wing, which can be directed to any protected zone or zones on that side of the aircraft.

C. Individual System: A separate supply of agent for each protected zone or zones. The decision to provide a reserve supply (second shot) of agent should depend on the probability of occurrence of fire for the airplane. The Air Force has stated that aircraft with 4 or more protected zones should carry a reserve, and the CAA requires a reserve shot on all multi-engine airplanes carrying passengers for hire.

1. 552 Distribution System Design

A. Conventional Systems: The selection of the distribution system should be made with full cognizance of the hazards to be covered. The distributor system (i. e. discharge nozzles fed individually by lines from a central manifold) is the most efficient (Ref. 11E). The complexity of such a system, however, may show it in a less favorable light than the loop or ring system (i. e. orifices drilled in a distribution line, the loop being fed

from one end, and the ring being fed from a point on a continuous circle of line) as far as weight, complexity of manufacture and types of hazard to be covered are concerned.

B. High - Rate - Discharge Systems: For HRD systems, open feed lines are recommended by the CAA. In high airflow zones, outlets should be located as far upstream as possible with the discharge directed across the air stream and slightly downstream such that a helical spray pattern is produced. In zones of low or negligible airflow, the outlet location is not critical but a location at the top-center of the zone with the agent directed downward is suggested.

1.553 Line & Orifice Areas

A. Conventional Systems - CO₂: Because of high storage pressure, the orifice areas of a system seem to act as the flow control with system flow losses as a minor effect. Because of this, distribution systems of 50 ft or less can be satisfactorily computed by the following factor:

Line Area = .10 sq in-lb CO₂/sec.

Orifice Area = .072 sq in-lb CO₂/sec.

(72% of equivalent line area)

Min. Orifice Size = 1.16 in. diameter

All lines upstream of direction valves should be 4,000 psi burst and lines which are open should be 2,000 psi burst.

Care should be taken to insure that all valving and/or equipment in the distribution line has an appropriate flow rate.

Expansion at fittings, tees, etc., should be checked to insure that not over 150% of the inflow area exists downstream. 130% is accepted as the safest target value. If overexpansion occurs, snow will form and plug the lines.

CB & CH₃Br: In low pressure systems such as these, line and fitting losses become a greater effect in the discharge rates and distribution than was true with CO₂. Within reasonable line lengths, however, the following area factors can be used with fair accuracy.

Line Area = .07 sq in-lb agent/sec.

& Orifice Area = .05 sq in-lb agent/sec.

(72% of equivalent line area)

Min. Orifice Size = 1/32 in. diameter

It is generally conceded that a system designed to these factors (especially a complex layout) should be carefully tested or analyzed for time of discharge and distribution.

B. High - Rate - Discharge Systems: For HRD systems of all types, feed line cross-sectional area is dependent upon the rate desired and upon system volume considerations. The minimum diameter of the feed line is established by the re-

quired rate; the maximum diameter of the feed line by the need for keeping the system volume at a minimum. Specifically, with the propelling gas in a system pressurized to 400 psi, the "volumetric efficiency" should be at least 0.50; that is, the original volume of the propelling gas in the system should be at least one-half the volume of the entire system, including that of the agent container.

It is recommended that for HRD systems the feed lines be open. No nozzles or series of perforations are required. It is believed that the unrestricted release of the more volatile liquid agents, as well as carbon dioxide, can be relied upon for adequate distribution, provided the outlets are properly located.

Because of the very limited practical experience with and consequent limitation on HRD system design knowledge, it is particularly important that any such system be carefully tested for time of discharge and distribution.

1.554 Power Plant Extinguisher System

A. Areas to be Protected: A fixed fire extinguisher system should be provided for:

1. The power section.
2. The accessory section.
3. The induction system when the engine is carburetor equipped.
4. The oil cooler and the coolant radiator, when they or the duct leading to them are located in a fire zone, not separated by a fire resistant fire seal or where directly in the path of flames from a fire which might exist in a fire zone.
5. The zone aft of the firewall, when the presence of combustible fluids and sources of ignition make this zone a fire hazard.
6. The entire engine section in liquid cooled installations.

B. Techniques of Discharge:

1. The power and accessory sections' fire extinguishing agent should be discharged so as to flood the entire compartment simultaneously. The proper distribution such that all air leakage into the zone is diluted 50% by extinguishing agent will result in a system 100% effective.
2. The agent should be discharged into the induction system upstream of the point where the fuel is injected on carburetor engines. Nozzles should be arranged so as to completely fill the duct with agent.
3. When the zone aft of the firewall is to be protected, a fire extinguishing system should be installed which will completely flood the compartment with fire extinguishing agent. It has