

RATIONALE

This document provides guidelines for the design, installation, and testing of aircraft vent system flame arrestor installation. In the absence of specific regulatory direction, this document provides a basis for standardized test methods.

1. SCOPE

The scope of this document is to provide pertinent information on demonstrating the performance of Flame Arrestors, also known as Fuel Vent Protectors (FVPs), in preventing the propagation of a deflagration when the arrestors are subjected to aerospace-representative flames produced by the venting of flammable gas through the arrestor. Test procedures for two separate combustion-loading profiles are presented herein: The flame hold test condition, and the flame propagation test condition. For the flame hold test condition, the applicability of two separate critical flows is discussed in which one flow results in the greatest flame arrestor temperature and a second flow results in the greatest temperature of the surrounding structure. These guidelines are necessary for OEMs and fuel/vent system designers to validate the flame arresting-performance of the subassemblies comprising of the flame arrestors and relevant surrounding structures in an installation environment representative of the actual unique aircraft installation.

Flame arrestors are components of the fuel system plumbing and, as such, are subject to the same requirements of other fuel system plumbing components. This document presupposes that the flame arrestor is properly installed; note that existing documentation (refer to ARP8615) provides detailed guidance for testing a flame arrestor as a component of a system, including standard requirements for testing the installation of a flame arrestor.

Flame arrestors are installed on other aircraft system installations besides fuel vent systems. These include: fuel tank inerting system (within the distribution system at the tank entrance), electrical pump inlets and external aircraft drain masts. Although only the fuel tank vent system installation is specifically addressed in this document, portions of the detailed flame test procedures may be useful to qualify flame arrestors in other applications, e.g., the flame propagation test which is applicable to flame arrestors installed in the inerting system.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of the other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

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Documents

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2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR1662	Minimization of Electrostatic Hazards in Aircraft Fuel Systems
ARP5412	Aircraft Lightning Environment and Related Test Waveforms
ARP5414	Aircraft Lightning Zones
ARP5416	Aircraft Lightning Tests Methods
ARP8615	Fuel System Components: General Specifications For

2.1.2 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

81 FR 41200	Fuel Tank Vent Fire Protection, 2016
AC 20-53B	Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning
AC25.981-1C	Fuel Tank Ignition Source Prevention Guidelines
AC25.975-1	Fuel Vent Fire Protection
AC25-8	Auxiliary Fuel System Installations
14 CFR Part 25	Airworthiness Standards: Transport Category Airplanes

2.1.3 Other Publications

CS25.975-26	Large Aeroplanes, Fuel tank vents, 2020.
EN ISO 16852	Flame arresters - Performance Requirements, Test Methods and Limits for Use
MIL-STD-464A	Electromagnetic Environmental Effects Requirements For Systems
MIL-STD-810	Environmental Test Methods and Engineering Guidelines
RTCA-DO-160	Environmental Conditions and Test Procedures for Airborne

Glassman, I.G., et al. *Combustion*, 4th ed. Academic Press, 2008.

2.2 Definitions

EQUIVALENCE RATIO: Sometimes referred to as stoichiometric equivalents—e.g., an equivalence ratio of 1.8 may be referred to as “1.8 stoichiometric equivalents”—is the ratio of fuel-to-oxidizer in a given gaseous mixture relative to the stoichiometric ratio. Defining the mass fraction of fuel in a mixture as y_{fuel} , the mass fraction of oxidizer as y_{ox} , and the mass fractions of fuel and oxidizer at the stoichiometric condition as $y_{\text{fuel,st}}$ and $y_{\text{ox,st}}$, then the equivalence ratio, written as the variable ϕ , of a mixture can be calculated per Equation 1. Equivalently the equivalence ratio may be expressed in terms of the mole fraction of fuel (x_{fuel}), the mole fraction of oxidizer (x_{ox}), and the mole fractions of fuel and oxidizer at the stoichiometric condition ($x_{\text{fuel,st}}$ and $x_{\text{ox,st}}$) also given in Equation 1. Note that $\phi = 1$ at the stoichiometric ratio; equivalence ratios above 1 are fuel rich, and equivalence ratios below 1 are fuel lean. An example calculation of the fuel/air ratio required for a specific equivalence ratio is given in Appendix A.

$$\phi = \frac{[y_{\text{fuel}}/y_{\text{ox}}]}{[y_{\text{fuel}}/y_{\text{ox}}]_{\text{st}}} = \frac{[x_{\text{fuel}}/x_{\text{ox}}]}{[x_{\text{fuel}}/x_{\text{ox}}]_{\text{st}}} \quad (\text{Eq. 1})$$

EVACUATION TIME: The time required by the occupants to move, when they recognize the danger and start to evacuate, from the hazard area to a safe region.

FIRE RESISTANCE: The capability of a material or component to perform its intended functions under the heat and other conditions likely to occur at the particular location and to withstand a flame for a minimum duration of 5 minutes.

FLAME ARRESTOR: A passive device designed to prevent the propagation of a flame front from entering a compartment or volume where a flammable mixture exists while allowing for the flow of fluid through the arrestor—ideally with minimal pressure drop across the arrestor. A typical flame arrestor is essentially a short length of tube with a portion of the tube interior filled with the Flame Arrestor Element.

FLAME ARRESTOR ELEMENT: The matrix structure internal to the element that performs flame arresting or flame holding. Typical flame arrestor element designs include crimped metal ribbon and metal screens.

FLAME ARRESTOR FLAME-SIDE: The face of the flame arrestor that, in the case of an ignition event, will be directly exposed to the flame front. Note this is the downstream face during flame hold testing.

FLAME ARRESTOR PROTECTED-SIDE: The face of the flame arrestor that, if the flame arrestor prevents flame propagation, will not come into contact with the flame. Note this is the upstream face during flame hold testing.

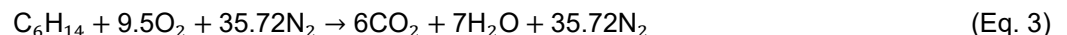
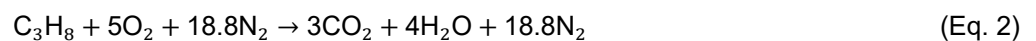
FLAME FRONT: The combustion zone within which the chemical reaction between fuel and oxidizer occurs.

FLAME HOLDING: The ability of a flame arrestor to prevent the propagation of a flame front down a passage while the arrestor is exposed to a sustained flame of pre-determined duration (e.g., 2 minutes 30 seconds)

FLAME PROPAGATION: The spread of a **flame** in a combustible environment outward from the point at which the mixture ignited.

IGNITION SOURCE: A source of sufficient energy to ignite a fuel/air mixture. Ignition sources of relevance to aerospace applications include electrical arcs, filament heating, friction sparks, electrostatic discharge, and hot surfaces of temperature equal to or greater than the autoignition temperature.

STOICHIOMETRIC FUEL/AIR RATIO: The mixture of fuel and oxidizer species that balance the chemical equation of the combustion reaction such that all fuel and oxidizer components can be converted into CO₂ and H₂O. The stoichiometric chemical equations for propane (C₃H₈)-air and hexane (C₆H₁₄)-air combustion are shown in Equation 2 and Equation 3.



SURVIVABLE CRASH: An impact where a majority of occupants sustain no fatal injuries.

3. DETERMINATION OF REQUIREMENTS AND APPLICABILITY

Determining the applicability of a flame arrestor in a fuel vent system begins with the type of application and the installation on the air vehicle. Two criteria govern the applicability of a flame arrestor to an aerospace vent system:

1. The gas in the vent system may, under certain conditions, be flammable and, if the gas were ignited, the resulting flame may propagate to other areas of the fuel system.
2. An ignition source may be present. Potential ignition sources include exterior heat sources (such as, in the case of a survivable crash, a fire near the vent flame arrestor) and lightning strikes.

These conditions should include realistic combinations of environment and flow parameters, rather than a theoretical combination of conditions that cannot exist at the same time; for example, note that the lightning threat is altitude-dependent as described in ARP5414B. If both of the above criteria may be true, then a flame arrestor is recommended in order to quench an ignited flame and thereby prevent the propagation of the flame to other areas of the fuel system. Additional factors influencing the requirements on the flame arrestor are as follows. The source of the fuel is an important parameter to consider, as different flame conditions can exist based on whether the fuel may be consistently flowing through the arrestor for an extended duration. The possibility of a flammable fuel/air mixture coming into contact with the exterior of the flame arrestor must be considered when assessing the potential for hot surface ignition in regions adjacent to the flame arrestor. The subsequent requirements definition also depends upon such parameters as maximum airflow versus pressure drop; maximum fuel flow pressure drop for the refuel failure case; fuel/air mixture flow for a flame holding event; whether any surfaces on the device are in contact with the fuel system ullage such that elevating the temperature of the surfaces may ignite the ullage; adjacent heat sink properties; and other environmental conditions such as vibration, flutter-induced loads, and contaminants. Typical flame arrestor installations are shown in 3.2.

3.1 Flame Arrestor Expected Performances

The flame arrestor is a component added to enhance the safety of a primary operating system. To that end, the addition of the flame arrestor must not interfere or diminish the operational effectiveness of the existing system. Thus the design requirements can be split into three categories: Flame Arresting, Pressure Drop (fluid flow and integration), and Other Environmental Considerations (e.g., temperature and icing).

3.1.1 Requirements on Flame Arresting Performance

3.1.1.1 Flame Protection

The function of the flame arrestor is to prevent a flame from entering the fuel tank creating a further hazard (i.e., a fuel tank explosion). Flame arrestors may be used to delay the propagation of fires due to a crash and potential subsequent ground fire, and to prevent the deflagration flashback that may result if a cloud of vented fuel is ignited by electrostatic discharge or lightning at the exterior interface of the vent system. Flame arrestors function by quenching the flame within the matrix of the unit, this passive heat loss enables the arrestor to prevent a flame from propagating through the arrestor and, in the case that fuel is continuously flowing through the arrestor, hold a flame at the outlet. A key element of their operation is that a flame does not propagate through the arrestor for all possible and practical conditions relevant for the system in which the arrestor is installed. The arrestor divides the plumbing system into two sections: the Flame-Side in which ignition sources may exist to ignite the venting flow, and the protected-side. This is shown schematically in Figure 1.

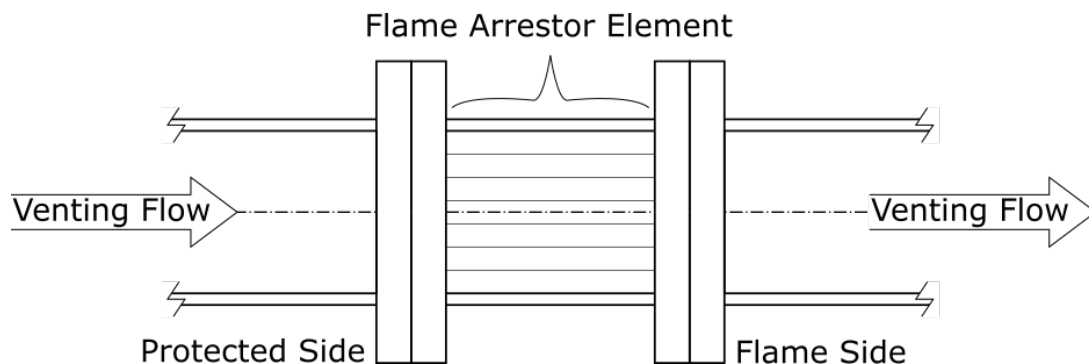


Figure 1 - Flame arrestors divide the fuel system plumbing into a flame-side, and a protected-side

Flame arrestor functionality must be demonstrated through test under conditions directly relevant to the given installation or by similarity to a previously tested system. When considering the operating limits of a flame arrestor in a given installation, two extreme cases are sustained flow and zero flow following a fuel-venting event:

1. Sustained flow: In the event of a survivable crash, a flame arrestor will provide additional time for the safe evacuation of the aircraft. In this case, a flammable fuel/air mixture may be flowing through the flame arrestor and this mixture may ignite on the flame-side of the arrestor resulting in a flame that is anchored by the flame arrestor for an indefinite period of time. The flame will constantly heat the arrestor and may, given enough time, directly ignite the gas in the fuel vent system on the protected-side of the arrestor or, if present, in a flammable environment in contact with the exterior of the arrestor as shown schematically in Figure 2. In order to validate that the installed flame arrestor will provide the required amount of time for safe evacuation, the installed arrestor must be demonstrated to prevent ignition on the protected-side of the arrestor and, if the relevant surrounding surfaces may be in contact with a flammable environment interior to the protected volume, to keep the exterior surface temperatures below the autoignition limit for a required duration as determined by the OEM under worst-case test conditions. The worst-case flow rate is not trivial because two failure mechanisms must be considered: heating of the arrestor and heating of the surrounding structure; these mechanisms are discussed below in detail. Validating the performance of a flame arrestor for sustained flow is the flame hold test.

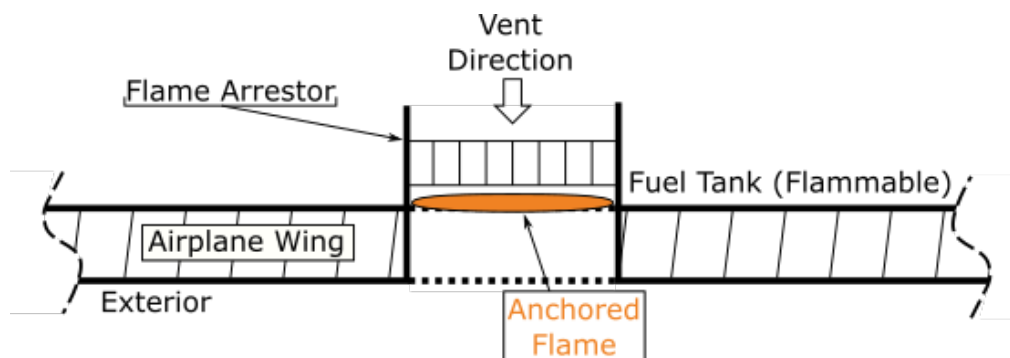


Figure 2 - Fuel vent flame arrestor preventing the upstream propagation of a flame towards the protected-side, under sustained flow through the arrestor

2. Zero flow: In the event of ignition when a flammable fuel/air mixture is not flowing (or flowing very slowly), a flame will occur that may flash through the arrestor and threaten accidental ignition of the protected volumes. In this case, the gas inside the flame arrestor, the gas connecting the arrestor to the ignition source, and the gas linking the arrestor through the fuel system to a volume which must be prevented from igniting are all filled with a stagnate fuel/air mixture of maximum flammability; see Figure 3. This is an extreme in that in the absence of gas flow through the arrestor opposite the direction of flame propagation, a propagating flame will obtain a maximum speed in the arrestor-fixed frame of reference. Without flow, however, if the arrestor quenches the initial flame front the flame will be extinguished quickly after the fuel that has vented has burned. In order to validate the installed flame arrestor will prevent the propagation of a flame to other connected volumes, the arrestor must be demonstrated to prevent the propagation of flame from the flame-side to the protected-side of the arrestor under worst-case conditions as discussed below and determined by the OEM. Validating the performance of a flame arrestor for a volume of stagnate fuel/air is the flame propagation test.

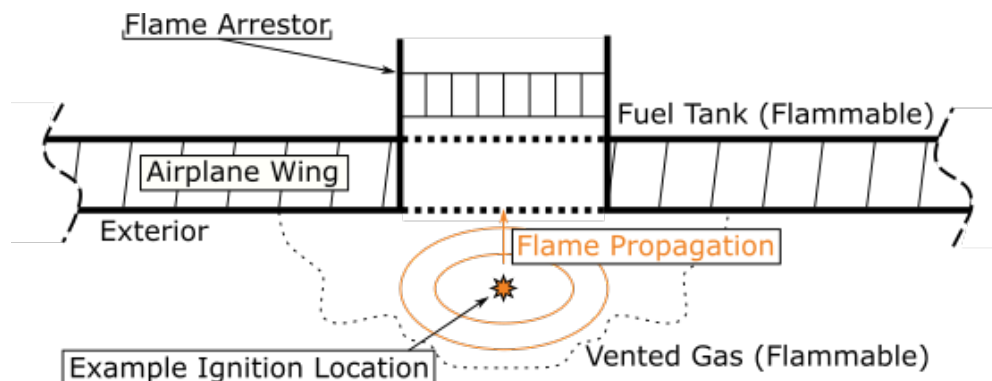


Figure 3 - Schematic of worst-case flame propagation test condition

These two extremes bound the flame profiles to which a fuel system vent flame arrestor may be subjected.

Due to the stringent pressure drop requirements and weight and volume constraints, aircraft flame arrestors are not typically designed to operate for an infinite period of time (in the flame hold case) or infinitely quickly propagating flames (in the flame propagation case). Some flame arrestors, by nature of their geometry, have a tendency to extinguish a flame when held under certain conditions. However, the ability of most aerospace flame arrestors to prevent the propagation of a flame is a time limited function. This time is usually specified in the OEM's specification for the flame arrestor and is based on the time requirements for the safe evacuation of the aircraft.

The FAA had established that airplane evacuation must be accomplished within 90 seconds. This duration did not consider the effects of a fuel tank explosion on the ability of passengers to leave the crash site or the safety of emergency crews. The flame arrestor performance requirements should be based on the time it would take for an external fire to otherwise cause a tank explosion due to penetration of the under surface of an empty wing tank or heating of the fuel tank surfaces to the ignition temperature of the fuel.

Burn through of the fuel tank surfaces would not be expected for a time period of at least 5 minutes for fire resistant materials. However, advanced materials do not necessarily provide equivalent burn through characteristics to those materials. Fuel tanks are not required to be made of fire resistant materials except for some dedicated areas and for fuel tank access panels. Therefore, burn through of dry tank surfaces is possible in less than 5 minutes.

Based on the 90 second maximum evacuation time, aircraft manufacturers developed a fire protection scheme by which they defined a maximum flame holding time. That scheme may take into consideration the additional time for passengers to exit from the crash scene and the various thermal constants of the installation submitted to the heat sources: 2 minutes and 30 seconds is now the FAA requirement for the flame arrestor system as required in the final rule "Fuel Tank Vent Fire Protection" of 81FR41200 and in 25.975(a)(7) and CS25.975(a)(7).

This time is based on the worst-case conditions regarding fuel vapor emissions from the vent system and is, therefore, conservative; the actual effectiveness of the flame arrestor should exceed the time for wing skin penetration.

The flame propagation case is characterized by relatively short time scales (e.g., test times typically less than 1 second) and quickly propagating deflagrations. In this case, the flow of hot gases through the arrestor is largely dominated by the flow induced by the combustion event, with faster flow resulting in less time the hot gas spends in the arrestor and therefore less time for the gas to be cooled by the arrestor core.

3.1.1.2 Considerations about Lightning

Lightning presents two additional threats to the proper functioning of fuel system vent flame arrestors: lightning is an energetic ignition source, and the currents and voltages associated with lightning may create an electric arc or similar energy source capable of igniting a flammable mixture in the protected volume behind the flame arrestor. The requirements imposed on arrestors to prevent these threats are discussed below.

1. Lightning represents an energetic ignition source that may result in flame propagation owing to the pressures, temperatures, and ion concentrations associated with lightning. This threat can be mitigated by the placement of the flame arrestor. Fuel system vent flame arrestors shall be installed such that direct lightning attachment to the arrestor face will not occur. It is recommended that fuel system vent flame arrestors be installed in areas where direct attachment is unlikely (i.e., lightning zone 3).

In all installations where direct lightning is a threat, i.e., for arrestors installed in zones 1 and 2, fuel system vent flame arrestor performance must be demonstrated by passing the flame propagation test with lightning direct attachment as the ignition source. Additionally, fault tolerance must be shown for the arrestor preventing flame propagation.

For flame arrestor installation within a zone 3 area, testing may still be required but the installation is not required to be fault tolerant and the test specimens are not required to encompass a large variability of their geometric parameters and of their installation. The compliance may also be demonstrated by probability calculation (catastrophic fuel vapor ignition has to be less than extremely improbable).