**Fire suppression systems in aircraft: Their past, present & future**

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Fire suppressants are used as part of our everyday lives due to their ability to safeguard life and property. Until recently halons and other ozone depleting substances were commonly used, but for many ground based applications these have now been replaced. However, in aeronautics the challenge to identify suitable replacements for some applications has been difficult, particularly in relation to cargo hold protection. The following article will discuss the history of halon use and withdrawal, and the challenges we are facing to develop new aeronautical fire suppression systems.

**Halon historical use**

**What are halons?**

Halons are a manmade chemical compounds based principally on the elements of Bromine, Fluorine and Carbon. They exist in different variations that are used for different purposes, for example Halon 1001 (CH3Br) is used as a pesticide while Halon 1301 (CF3Br) is the halon variation mostly utilised as the fire extinguisher agent.

**Why are they used in fire suppression?**

Halon use is based on a relatively new concept of attacking the threat of fire. Fire can be described using the fire triangle, which represents the interaction of the three different factors required for a fire to occur; in its simplest form; Heat, Fuel and Oxygen. Traditionally it was believed that only by removing one or more of the sides of the fire triangle the fire will cease.

However as our understanding of fire chemistry improved the fire triangle morphed into a fire tetrahedron, incorporating free radical creation and chain branching reactions. This led to the concept of using chemicals capable of inhibiting the reaction and interaction between the elements of the fire triangle in order to extinguish the fire. Halons, which act in this way, offer an immense advantage when suppressing any type of fire over other chemical inhibitors as they are electrically non-conductive, pose no threat to human health and they are non-toxic, non-corrosive and leave no residue.

The aeronautical industry has always been concerned with the possibility of a fire on board. Due to their nature, aircraft are very vulnerable to a fire threat initiating as; they carry flammable liquid and other material that could act as fuel, they have numerous potential ignition sources like the heat of the engines or from the multiple electric components and they travel through the air which will constantly feed the threat. All these contribute to the fire triangle in this situation. The difficulty in reducing/ removing these factors resulted in the use of halon to suppress fire.

With the implementation of new types of propulsion, the turbojet and turbofan engines and the rise in the use of commercial aircraft as the predominant passenger transport around the 1950s the investigation and use of halon based suppression system as we know it today started developing (C.M.Middlesworth, 1952). Different analyses identifying the most effective and efficient halon based agent were produced, establishing in multiple reports, both by the Federal Aviation Administration (FAA) - (G.Chamberlain, 1970) (D.E.Sommers, 1970) and the Air Force Wright Aeronautics Laboratory (AFWAL) (G.Chamberlain and P.Boris, 1987), that halon 1301 is the most effective suppression agent available.

Currently in aircraft cargo holds a double release fire suppression system is utilized. The system is made up of two containers of halon and a communal stationary nozzles-tubing. The first stage is an instant high volume halon release so that the threat can be eradicated, and the second is a gradual halon release over a considerably longer time to allow the aircraft time to land safely by avoiding any potential re-ignition.

**The problem with halons**

Although halons are an outstanding fire suppressant agent during the mid-1970s further analysis revealed its environmental flaws. Following World War 2 the impact to human populations by human activity became both noticeable, with for example nuclear fallout and leakages, and measureable, where technology and collected data was up to the standards to produce reliable results. As concerns regarding the environment began to rise, specialist associations and movements like Greenpeace or Earth Day were formed to encourage the general population to take a more serious consideration of environmental threat certain human related activities caused. With the scientific data and the desire for a cleaner world from the countries and their citizens, a series of different world wide meetings took place resulting in new legislation like the Montreal Protocol in 1994 that ensured the environment will be protected.

Halons, part of the CFC family, were not considered to be a threat to the environment as under normal conditions as their reactivity is very low. However, as demonstrated in the 1970’s (M.J.Molina & F.S.Rowland, 1974), because of their low reactivity they are able to rise to upper parts of the atmosphere. At the stratosphere (+/- 50 km) where the UV radiation from the sun is stronger they break down due to the intense photon exposure causing chorine free radicals be released. These radicals then react very strongly with the ozone molecules situated at this altitude causing the ozone molecules to be destroyed and hence the ozone layer to diminish.

The ozone layer ensures that a large percentage of the UV radiation from the sun is prevented from entering our atmosphere. This is important to all life on earth as it can be damaging. Considering the ozone depletion potential (ODP) halons substances have, and current emission levels, the natural replacement process of ozone is not strong or fast enough to stabilise the levels hence making the ozone protective layer thinner with time. An additional problem is more photons filtering through to the inner atmosphere contributes to different global warming effects, thus halons also fall into the category of substances with Global Warming Potential (GWP), though this is dealt with in the Kyoto protocol. Eliminating halon use is therefore a critical problem.

**The Montreal Protocol**

The legislative bodies came together in the Vienna Convention in 1985 to address concern over ozone depletion and this developed into an International treatment agreement. The Montreal Protocol was approved preceding the Vienna Convention and stated that by 1994 the use and production of Halon and other substances with ODP must be stopped. This adaptive agreement was accepted by strong influential industrial markets, like the USA and Europe, declaring the genuine desire of protecting the environment from manmade activities by the most technologically pioneering countries.

The agreement has been revised and adjusted based on new scientific data and therefore new substances are being constantly added to this restriction ban. Available CFC free technologies require much more weight and volume to be able to match the effectiveness of halon based fire suppression systems.

For “ground based” industry the adaptive process to “non-ozone-depletion clean technologies” has been a challenge but nonetheless attainable as variation in the volume and weight figures from the current equipment do not represent a critical problem. Thus there are a number of chemicals, notably Novec 1230, FM-200, and HF-125 that are used commonly in many fire suppression systems today.

However, for particular Industries like Aerospace, where the volume/weight taken up by fire suppression systems are extremely important, and where the commercial benefit might be jeopardised, an extension to adapt to the Montreal Protocol regulations was granted.

**EU regulations**

For this adaptive process to take part, but still be able to maintain security on board in the case of fire, halon based fire suppression systems are currently still being used in aircraft. Recycled and prior-ban halon storages have also been kept around the world to grant the appropriate time for a reliable definitive halon-free system to be designed.

European legislation has addressed halon phase-out by setting different targets for the aviation industry in which they expect alternative green fire extinguishing methods to be available for installation.

Fire suppression systems in aircraft having been generally been divided into 4 categories (Cargo compartments, Cabin and crew compartment, Engines/Power units and Lavatories).
On an aircraft these systems are independent of each other and use different principle and technology of fire suppression.

**Time frame for phase-out of halons**

Approaches vary depending on the area of the aircraft e.g. there is a great difference between requirements for fighting fires in engines versus lavatories. EASA has therefore applied different targets to these areas, shown in table 1 (P.Gordon, 2013)

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| Table 1. EASA commission regulation (EU) 744/2010 |
| Purpose | Type of Extinguisher | New Products Certification Dates | Complete disuse of halon |
| Cargo Compartments | Fixed | 2018 | 2040 |
| Cabin/Crew Compartments | Portable (Handheld) | 2014 | 2025 |
| Engines / Power Units | Fixed | 2014 | 2040 |
| Lavatories | Fixed | 2011 | 2020 |

**Suppression system validation techniques**

In order to validate potential eco-friendly halon substitutes the Federal Aviation Administration (FAA), in conjunction with other expert bodies, developed the Minimum Performance Standards (MPS). This set of tests take into consideration the different aspect of a fire behaviour and development on board an aircraft cargo hold and compares its results to halon performance to ensure an equal level of safety (ELOS).

For the four identified fire suppression systems a different set of MPS were created so that the specific needs could be targeted adequately. A brief overview description can be seen in table 2.

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| Table 2. Aircraft Fire Suppression Systems Minimum Performance Standards (MPSs) |
|  |
| Lavatory Fire suppression system MPS test (T.Marker, 2013) |
| Fire test | Extinguish successfully in 15s a containerised fire of 820 g of paper towels at 175°F in a test receptacle of aluminium (18in x 16in x 8in) without reigniting. |
|  |  |
| Handheld (cabin and crew compartment) Fire suppression system MPS test (H.Webster, 2002) |
| Hidden Fire Test | Indirect extinguishment by the handheld extinguisher of at least 9 out of 20 small cup fires (35mm diameter) in a five by four array (in a 2m x 2m x 0.5m container) in 60s.  |
| Toxicity/Seat fire test | Extinguish successfully a 3-seat aircraft component in a containerised TC-10 fuselage cabin simulator without reaching a hydrogen fluoride peak of 200ppm in the first 60s and a peak of 100ppm until 4.5min from beginning of test |
|  |  |
| Cargo Compartment Fire suppression system MPS test (J.W.Reinhardt, 2005) |
| Bulk-load fire test | Simulated fire inside a cargo compartment (56.6+/-2.8m3) packed up with cardboard boxes. Ensure temperature peak and time-temperature curve do not go above 377°C and 4974 °Cmin respectively during 2-5 min period after fire activation. Fire stabilised for at least 180min after the test. |
| Containerised-Load fire test | Simulated fire inside a cargo compartment filled with aluminium containers packed with cardboard boxes. Ensure the temperature peak and time-temperature curve do not go above 343°C and 7569°C-min respectively during 2-5 min period after fire activation. Fire stabilised for at least 180min after the test. |
| Surface Burning fire test | Simulated fire inside a cargo compartment with a tray (2ft x 2ft x 4in) of ignited jet fuel (2L) located in the middle. Ensure the temperature peak and time-temperature curve do not go above 293°C and 608°C-min respectively during 2-5 min period after fire activation.  |
| Aerosol-Can explosion test(Long version) | Simulated explosion inside a cargo compartment packed with cardboard boxes (Short version minus cardboard boxes) and an aerosol-can explosion simulator. Activation of simulator shall occur 2 minutes after suppression system activation. No evidence of overpressure or deflagration shall occur across 180 min.  |
|  |  |
| Engine/Power units Fire suppression system MPS test (FAA, 2010) |
| MPSHRe | Extinguish a simultaneous threat of pool and spray fire, in the core of an engine compartment -nacelle fire- simulator (min volume 1.83m3) with 2 different air flow conditions through it.  |

The European Aviation Safety Agency (EASA) and FAA work in conjunction on many programs as the majority of the operational aircraft come from these two regions, hence EASA has adopted the same MPS regulations.

**Identified halon replacements**

There have been significant improvements in handheld extinguishers (cabin & crew compartment) and in lavatory fire suppression systems, with alternative agents having passed the MPS screening tests. Since 2002 principal aircraft manufactures have been installing halon free fire suppression systems in aircraft lavatories using the ‘clean agent’ HFC-236fa which allows for a ‘drop in’ solution. For handheld extinguishers (cabin & crew compartment), adoption of the replacement agents will be swift. (L.C.Speitel, 2012)

In relation to the engine and cargo compartments no functional solution has been yet reached. HFC-125 has been investigated for the Engine/Power unit, however, it suffers from bad agent distribution and other candidates like the FK-5-1-12 or Novec 1230 have an insufficient volatilisation of the agent at low temperatures. Industry collaboration, in the form of the Engine/APU Halon Replacement Industry Consortium (IC) continues to look at this issue (M.Robin, 2014). Thus far no single exchangeable agent has passed MPS tests for cargo compartment fire suppression systems.

**Halon alternatives for cargo compartments**

Preliminary opinions of experts indicated that finding a “drop-in” alternative to halons in cargo compartments would not be possible as no alternative agent of equal characteristics was available. (W.M.Parson, 2003),

However, the industry is still in search of an easy and straight forward solution that won’t require large amendments to the existing systems.

2-BTP and FK-5-1-12 as well as the approved Environmental Protection Agency (EPA) substances of HFC-125, HFC-227ea have been tested, however, analysis from the FAA (D.Ingerson, 2008) indicates that all of these options fail to meet the requirements, mainly due to the inability to keep prevent overpressure rise in the aerosol-can explosion test. Other analysis also reinforced these results and indicated that in some cases the agent enhanced the threat from overpressure. (J.Reinhardt, 2007)

The newest approach to identifying a green fire suppression system has been a dual or multi-agent combination approach. Mixing water mist or fog with inert gases like Nitrogen could develop into a potential solution. This dual agent system takes advantage of water’s outstanding properties in the suppression of direct flames in fires, while the inert gas aids in ensuring the threat is controlled over time allowing the aircraft to land safely.

This option requires a complete redesign of the cargo compartment fire suppression system as the halon and water mist/nitrogen agent systems differ vastly in their; volume required, storage status and agent dispersal mechanism. This is therefore a great engineering challenge (ICAO, 2013).

As the only halon-free and eco-friendly potential substitute agent known to date and due to the impending deadlines on halon use in Europe/ worldwide the necessity of developing a new novel system based around a multi-agent approach seems, at this point, inevitable.

**LSBU & the EFFICIENT project**

In order to find a conclusive definitive halon-free fire suppression system for aircraft the European Commission under the Horizon 2020 - Clean Sky 2 Program, is funding the EFFICIENT project consortium. London South Bank University (LSBU) Explosion & Fire Research Group (EFRG), Cranfield University (CU), SP Sveriges Tekniska Forskningsinstitut AB (SP), Maelardalens Hoegskaola (MDH) and Airbus Group will collaborate with an aim to create an Environmentally Friendly Fire Suppression System for Cargo using Innovative Green Technology (EFFICIENT). The aim being to develop a system that can pass the MPS tests, and be utilised in next generation aircraft that require halon free systems for their certification. The EFRG at LSBU has an extensive experience in different aspects of domestic/industrial and aeronautical fire safety which is hoped will complement the consortium expertise in aeronautics and fire safety science towards this new challenge.

**Challenges to be overcome**

The first major challenge for LSBU will be to test proposed agent/ agent mixture candidates. To be able to identify agent extinguishing concentration levels for flames a cup burner test method will be utilized. However, this provides only a guide of probable extinguishing concentrations and has been little used for double/ multi agent mixtures.

For a combination of mist and gas, for example, different measuring devices will be required for each individual element, and ratios will need to be carefully monitored. Novel laser measurement techniques such as those used in meteorology may prove useful.

Characterising the distribution of the agent will also be an important challenge to overcome. In the cargo compartment of an aircraft different configurations of cargo loading are possible. As represented in the MPS, loading devices units (LDUs) or netting could be used hence the appropriate distribution of agent(s) must be ensured. The density, velocity, and pattern as well as droplet size (for liquids), of the agent(s) will all need to be defined. A pressure vessel test will also be used to evaluate the agent(s) ability to inhibit reactions and overpressures, and environmental test facilities will assess the system’s ability to offer the same level of protection at ground level as when flying (cruise altitude, temperature, and pressure).

The final challenge for the EFFICIENT project will then be to integrate the system inside an aircraft. Limited space and weight caps will be the biggest constraints to overcome. Halon offered the advantage that a relatively small amount of agent, without any type of special dispersion conditions, could easily satisfy all the MPS required levels. Trying to adapt the new system to fit into the space of the old one will pose a considerable obstacle. Mechanical integration, using gas inerting devices and control and monitoring electronics will be required to ensure the agent is ready and in a suitable condition to be released. Hence there will be a need for intelligent assembly or even innovative redesign. (Pagliaro, 2014)

**Conclusions**

HGHalon significantly contribute to ozone depletion, and the increase of global warming. While ground based technologies have been able to adapt quickly to the environmental legislation banning these environmentally dangerous chemicals, the task of finding a replacement is far more difficult for some applications in aeronautics. Some improvements have been made for small scale applications like fire suppression systems in lavatories or handheld extinguishers but critical fixed fire suppression systems used in cargo compartments are still utilizing halon. The challenge to identify an agent with equal level of safety to halons, both in terms of flame inhibition and overpressure prevention has proved problematic. LSBU has begun targeting this engineering challenge and over the next few years as part of the EFFICENT project, led by Cranfield University, aims to assist in the production of innovative green technology that can be implemented into the new generation of aircraft. The very recent and positive news about the regeneration of the ozone layer (McGrath, 2016) reveals the replacement of halons and other ozone-depleting substances is having a clear and positive benefit for the environment that is worth continuing to pursue.

For more information or a preliminary discussion about working with LSBU’s Explosion & Fire Research Group please contact: reibusiness@lsbu.ac.uk

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