Hazardous Area Classification of Potentially Explosive Atmospheres During Aircraft Fuelling Operations

Andrew Garrison, Consultant, RPS, 105 Dalton Avenue, Birchwood Park, Warrington, WA3 6YF, UK

There are approximately 4,900 airports in the world that operate flights. The provision of fuel for the 155,000 daily commercial jet fuelling's at these airports poses significant safety challenges and the Energy Institute Aviation Committee identified a need to standardise the hazardous area classification of potentially explosive atmospheres around commercial jet aircraft fuelling across the world. This is due to the inconsistency or lack of classification around fuelling operations in different airports. This paper is a summary of the findings from an Energy Institute Aviation Committee funded joint industry project, the aim was to provide prescriptive guidance to the aviation industry in the form of direct examples for fuelling operations, similar to those direct examples provided in the Energy Institute Model Code of Safe Practice Part 15, EI15 (Area Classification for Installations Handling Flammable Fluids) 4th Edition.

The project involved a comprehensive literature review of relevant stakeholder documentation from around the world and from this, a set of direct examples were developed which illustrate the type and extent of potentially explosive atmospheres around aircraft fuelling operations. The draft direct examples were then made available for review by the Energy Institute Area Classification Working Group and the Energy Institute Aviation Committee, whose members include BP, Total, Chevron, HSE, Shell and ExxonMobil. Following this input the direct examples were refined and the decision made to ensure they were applicable in all climates from Dubai to Siberia. The possibility for a misted release from the pressurised fuelling system was considered and full justification provided on the decisions made.

The research report on Aviation Fuelling Hazardous Area Classification prepared by RPS which contains the direct examples was published in July 2017 by the Energy Institute. This paper will consider the potential impacts of the direct examples on fuelling operations and discuss the potential methods in which they could be implemented.

Keywords: Jet A-1, Hazardous Area Classification, Fuelling, ATEX, Aircraft, Explosive Atmospheres, DSEAR

Introduction

In the UK, airports have responsibilities under the Health and Safety at Work Act 1974 to secure the safety of persons at work and public from hazards arising out of activities on their premises. Therefore they have a duty to be complaint with the Dangerous Substances and Explosive Atmosphere Regulations 2002 (DSEAR) as they handle aviation fuel, a dangerous substance. DSEAR requires that a risk assessment is performed and where appropriate Hazardous Area Classification (HAC) is undertaken in areas where a potentially explosive atmosphere might exist.

The Civil Aviation Authority document CAP 748 outlines the requirements for licensees to perform HAC for the aircraft fuelling operations, an extract of which is below:

DSEAR regulations define zones in which a potentially explosive atmosphere might exist. Licensees should establish the circumstances in which such an atmosphere might be present in the process of fuel storage, management, handling and distribution at the aerodrome, and should develop procedures to mitigate the associated risks.

The Energy Institute (EI) Aviation Committee identified a need to standardise the classification of potentially hazardous zones around commercial jet aircraft fuelling across the world.

RPS were given the task of providing technical assistance to support the preparation of HAC guidance on the potentially flammable zones that may exist around jet aircraft fuelling operations.

The EI research paper provides guidance for the size and nature of zones, using the direct example format given in EI15 4th Edition. The zones and their hazardous extents are taken from the literature reviewed and applied pragmatically to reflect the nature and working environment of the aircraft fuelling equipment.

The EI research report was written with Jet A-1/Jet A as the process fluid. If an aircraft's fuel tanks are filled with lower flash point fuels (e.g. TS-1 or AVGAS) then spills and vent vapours will have a higher risk of forming an explosive atmosphere and a specific study must be carried out to determine the extent of any hazardous zone.

This paper includes extracts from the final EI Research Report, Aviation Fuelling Hazardous Area Classification, July 2017 but is not exhaustive. The complete report can be purchased on the Energy Institutes website.

Methodology

RPS had an initial meeting in March 2016 with the EI Aviation Committee where information was gathered on aircraft fuelling operations. RPS were shown dispenser and refueller equipment located at the ASIG facility and then witnessed an aircraft being refuelled by a dispenser at Manchester Airport to aid in their understanding of the process and the potential sources of release.

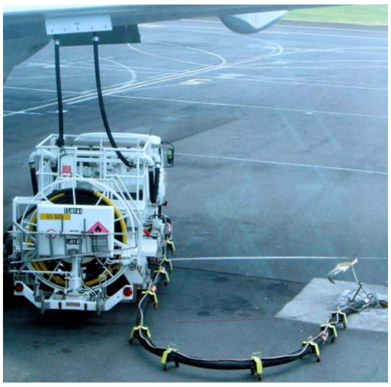

Figure 1 – Photograph of a Fuel Dispenser Fuelling an Aircraft

RPS then conducted a technical review of available literature and documentation, supplied by the Energy Institute Aviation Committee and other sources. The following operations were considered in the development of the HAC:

a) Aircraft and fuelling equipment in position ready to perform the fuelling operation,

b) Performing the fuelling operation,

c) Equipment in standby with no connections made to a hydrant or aircraft.

Following this technical review, RPS presented its findings to the Energy Institute Aviation Committee at a meeting in Prague on the 19th May 2016. Here RPS proposed the options for direct examples for the operations listed above and during the meeting, opinion was taken to construct a set of worldwide direct examples which could be applied to any aircraft fuelling operations, independent of the ambient temperature. Acceptance was gained and technical feedback given.

Properties Jet A-1

Jet A-1 has the following hazardous material properties pertinent to HAC:

- Relative Density:	>5 (relative to air) [1]
- Flash Point:	> 38°C
- Ignition Temperature:	>220°C
- Vapour Pressure at 20°C:	<0.1 kPa
- Lower Explosive Limit (LEL):	1%
- Gas group:	IIA[2]
- Temperature Class:	T3

The flash point provided is a minimum and varies widely in industry depending on the composition of the Jet A-1 with flash points of up to 70°C recorded. For Jet A-1 to be sold it must have a flash point equal to or in excess of the mandated 38°C. Jet A-1 has a low vapour pressure, in temperate climates like the UK, there will be no hazardous area if the fuel is at ambient temperature and pressure. If Jet A-1 were to be heated above its flash point it does not evaporate easily and therefore is unlikely to create a large flammable atmosphere when located outdoors in the open air.

The HSE[3] report AM5204 agrees that the possibility of explosions generated by Jet A-1 following a release is very small. It notes that if the release were to be in a confined area, like a pit or duct, an explosion is possible but that the Jet A-1 would still need to be raised above its flash point. The same report includes an incident review which identifies the causes of a number of incidents involving Jet A-1, the majority being catastrophic failures (e.g. pit valve shear, coupling strikes and hose ruptures) and therefore not considered for HAC.

One way in which Jet A-1 could create an explosive atmosphere without being heated above its flash point is if it were to be release as a mist. The HSE have shown that flammable liquids can be released as a mist and ignited below their flash point[4]. But the HSE report AM5204 points out that if a flammable spray were to be ignited, it is more likely to result in a flash fire followed by a pool fire. This may not be the case if a mist were to be generated in a confined space, which may be the case if a mist is generated due to splashing within a vessel ullage (i.e. tanker filling).

The direct examples within the EI Research Report are not provided with a maximum ambient temperature as they apply to all climates. For climates where jet A-1 would not reach its flash point of 38°C these direct examples may be onerous.

[1] Shell MSDS, Product Code 002C0364 Shell, 2016
[2] BS EN 60079-20-1 Material characteristics for gas and vapour classification — Test methods and data, BSI 2010, info taken for Kerosene.
[3] AM5204, Quantified Risk Assessment of Aircraft Fuelling Operations, July 2000
[4] RR980, generation of flammable mists from high flashpoint fluids: Literature review.

RPS Main Conclusions from the Literature Review

Releases from joints (flanges, screwed fittings, valve glands etc.) in the pipework on the refueller and dispenser were considered and proved to be the most difficult to classify. Leaks of Jet A-1 from connections could either be released as a stream of liquid which could form a pool or be released as a mist. Whether it formed a stream of liquid or a mist depends on the pressure and the release orifice, in the majority of cases a leak in a flange leads to a stream of liquid (dripping) rather than a mist. For a mist to occur the release orifice must be of a certain geometry to allow for the droplets to be aerated rather than coalesce together. Pressures up to 10 barg are common in fuelling vehicle pipework.

In the majority of cases a leaking joint will release its contents in a stream of liquid which will then form a pool of Jet A-1. If the temperature of Jet A-1 exceeds its flash point of 38°C, a flammable atmosphere will form above the surface of the liquid. RPS reviewed experiments[5] performed by PTB during the literature review. The PTB experiments looked to determine the extent of the flammable atmosphere from pools of Jet A-1 at 50°C. The flammable vapours were measured as only being above the LEL of Jet A-1 (<1% vol) just a few mm above the pool, above this they were suitably diluted as not to be explosive (See Section 3.1 of PTB-EX-2e). Such a thin layer of flammable vapour would not give rise to harmful explosion pressure effects (See Section 4.2 of PTB-EX-2e). Therefore, a pool of Jet A-1 in the open area of an airport apron is considered a slow growth rate fire risk, rather than a flash fire or explosive risk and so can be considered a release of negligible extent and therefore Non-Hazardous[6].

Having considered the potential for a release to be released as a stream of liquid and pooling, the RPS team moved onto consider the misting scenario for joints in the pipework. This is a hot topic for discussion in industry and there is minimal information when compared to that of gaseous releases. RPS reviewed available literature on mist generations to aid them in determining the classification for the direct examples.

Roger Santon's paper on Mist Fires and Explosions[7] makes note of seven incidents involving kerosene, a main component of Jet A-1, and one incident involving aviation fuel where a mist explosion occurred. It should be noted that in none of these incidents was a mist generated from a pipework joint. But the incidents support that mist generation of Jet A-1 is possible. This is further supported by experiments conducted by the University of Cardiff in report MH1575, that a mist cloud of Jet A-1 can be produced and ignited from pressures as low as 1.7 barg. It also showed that radial extents could be as large as 1.5 m for pressures between 5 – 10 barg. But these results are from engineered orifices designed to generate a mist, such geometry is unlikely to occur from a leaking pipework connection.

There have been no reported incidents of explosions following a misted release from the pipework on an aircraft fuelling vehicle that have been mentioned in the literature reviewed. This is despite the high number of fuelling operations which occur each day around the world, (c 100000 commercial fuelling operations). Therefore there must be a number of factors which have contributed to the lack of incidents.

One factor might be the effect of orifice geometry on the generation of fine droplets able to form a flammable mist. All the tests where a flammable mist was formed used a circular hole drilled into a metal plate. In reality, the more complex orifices arising from a flange gasket or screwed joint failure will behave differently and may result in less of the spray forming fine droplets.

Another factor to consider is that the flow of Jet A-1 fuel through the fuelling vehicle is controlled by a dead man's switch and the system is continually manned. Therefore any release would be quickly identified by the operator and they would release the dead man's switch, stopping the flow of fuel and therefore removing the source of the release. If a flammable mist were to form, it would be clearly visible as it would be optically dense when approaching its LEL. Unlike on a typical industrial plant where operations are performed remotely from a control room and a release may not be identified until the next plant tour by an operator.

All the equipment used for aircraft fuelling is extremely well controlled throughout its lifecycle from specification to repair, thus reducing the probability of leaks. Industry standards have been created for the design, manufacture, installation, inspection and maintenance of aviation fuelling equipment and responsible users ensure that this equipment meets those standards. However, there is no external enforcement of these standards.

All the components are inspected and where required, tested by approved organisations to ensure that they are fit for purpose throughout their life. Such inspection and maintenance activity is prescribed by manufacturers and industry operating standards, with industry operating standard compliance programmes implemented at most commercial airports worldwide.

This has resulted in a low failure rate of equipment and so it is felt justified in using the derogation given in BS EN 1127-1[1] for describing the pipework joints and fittings that are not routinely disturbed as Technically Tight and therefore unlikely to leak meaning classification is not required.

BS EN 60079-10-1: 2015, Appendix G states that the risk assessments from mists should be backed up by references or operational experience. Through discussions with the Energy Institute Aviation Committee during a meeting in May 2016 in Prague, it was confirmed that members were not aware of any incidents of jet A-1 misting during fuelling operations.

[5] Hans Forster, PTB-EX-2e, Investigation into explosive hazards during the handling or kerosene Jet-A1 in tank farms and during the fuelling of aircrafts, October 2008

[6] See Section 4.3 of BS EN 60079-10-1 for an explanation on the negligible extent concept.

[7] R C Santon, Mist Fires and Explosions – An Incident Survey, IChemE Symposium Series No. 155, Hazards XXI

[1] BS EN 1127-1 - Explosive atmospheres - explosion prevention and protection, BSI, 2011, Annex B

Companies and organisations represented on the committee have extensive worldwide operations and a strong culture of sharing near miss/incident information on a global basis.

BS EN 60079-10-1: 2015, Appendix G also points out that not every leak will cause a mist formation, e.g. the leaks through broken flange gaskets that are the most common secondary grade of release, will in most cases cause dripping rather than mist. That means the likelihood of mists being generated through leaks in pipe joints, valves etc. should not be overstated.

Based on this operational experience and the other factors described above, it was decided that releases from joints in the pipework, transfer pumps on dispensers and refueller vehicles and hoses of fuelling equipment need not be considered for hazardous area classification. This is further supported by Quantified Risk Assessment of Aircraft Operations[8] performed by WS Atkins on behalf of the UK Health and Safety Executive which concludes that for any risk reduction measures to be proportionate they must cost no more than 7.9 p per operation. This cost-benefit analysis suggests a much better use of money would be to ensure that all hoses and hydrant couplers are visible to reduce the probability of a vehicle striking them.

Further discussion on the rest of the area classification for the direct examples can be found on the EI research report.

EI Research Report Outcome

Following the literature review and consultation with the Energy Institute Aviation Committee, the direct examples were agreed and developed. They identified a number of zones associated with aircraft fuelling, a short summary of which are included below.

A Zone 0 was identified within vessels due to the potential of splash filling creating a mist where dip pipes etc. are not installed. Around vents and sample points on the refueller a Zone 1 area was classified with a Zone 2 around the fuel hose connection point to take into consideration residual fuel release during coupling. Around the aircraft wing vents a Zone 1 sphere was designated due to vapours being ejected during fuelling and a Zone 2 to ground to take into consider the rare days where the wind speed is negligible and the vapours not sufficiently dispersed. For a full details of the direct examples please refer to the EI research report.

The EI research report includes AutoCAD generated HAC drawings which can be used to satisfy the regulatory requirements but have not been included in this report so as not to encourage their use without the user understanding the context in which they have been developed. RPS has placed the zones onto some typical scenarios to give a flavour of the direct examples but these are for information purposes only and are not to scale.

Figure 2 – Fuelling Dispenser Zoning

[8] AM5204 – Quantified risk assessment of aircraft fuelling operations, HSE 2000

Figure 3 – Aircraft Wing Vent Zoning

With regards to the dispensing equipment, there may be a requirement to certify any equipment located within the hazardous areas. More likely is that dispensing equipment manufactures will take this into consideration when designing the rigs and avoid installing equipment within these localised point source releases. Therefore there will be a limited requirement for certified equipment. If certified equipment is to be installed then a periodic inspection regime will need to be adopted. This may be as frequent as monthly visual checks on certified equipment and detailed yearly inspections due to the harsh environment in which they will be operating.

With regards to the zones associated with the aircraft fuel tank vents. Fuel apron operators will need to be wary of these zones which extend down to the ground. They could use visual warning devices like cones or tape to mark out these areas where ignition sources should be controlled i.e. vehicles not allowed to enter these areas. It is accepted that this would be impractical given the nature of airport aprons.

In-line with L138 Approved Code of Practice for DSEAR, a Hazardous Area Classification (HAC) drawing should be developed to aid in the visualisation of the zoned areas. The direct examples within the EI paper can be used to satisfy this requirement if suitable information is provided in the drawing with regards to substance properties.

The direct examples could be printed on large signs within fuel aprons so that they can be easy identified. Floor markings could be used but these would have to be generic and would not aid in the understanding of the elevation of the zones. Also due to the range of aircraft geometry, wing vents would not always be in the same position. It is common for the HAC drawings to be stored within a control room in a drawing rack or just laminated affixed to a notice board.

Implementation

One of the first hurdles in implementing the guidance within this document is determining who is going to take ownership of the implementation. Simply it is the duty of the employer who owns the airport apron (the aerodrome licensee) who is responsible for ensuring DSEAR is implemented on their site. The aerodrome licensee of the site may wish to delegate this duty to the operators of the installations, the supplier of the fuel or an third party consultancy.

Airport duty holders should firstly perform a DSEAR Risk Assessment for all activities involving aviation fuel. The risk assessment will consider the likelihood of a release of aviation fuel and in the UK, there will be minimal scenarios where an explosive atmosphere may develop based on the ambient temperature being much lower than the flash point of Jet A-1. This may not be the case for operations involving Av-Gas. The risk assessment will identify areas where HAC is required to minimise the risk.

In-line with Regulation 7(3) of DSEAR[9], where a HAC study has been carried out, this should be recorded in the form of a drawing which:

- Identifies the hazardous areas and types of zones;
- Shows the extent of the zones in both plan and elevation (i.e. illustrates the three-dimensional nature of the hazardous zone);
- Is supplemented by text giving information about;
    - The dangerous substances that will be present;
    - The work activities that have been considered;
    - Other assumptions made by the study;
- Is retained as part of the documentation in support of Regulation 5;
- Is considered whenever new equipment is to be introduced into a zoned area.

[9] L138 DSEAR ACoP, Para 354

The direct examples and guidance within the EI research report can be used to satisfy these requirements but the drawing needs to be visualised for those working in the area and they need to have awareness of what the drawing means with regards to the control of ignition sources. It is believed that this awareness is lacking and that training will be a key part in controlling ignition sources.

In addition to the creation of a HAC drawing, employers should alert people to the locations where an explosive atmosphere may occur and the need to take special precautions i.e. exclude ignition sources from the area like phones and vehicles. Signage is a simple method and could be local to the area or in a common place where multiple operators will see it. This could show the direct examples with annotated photographs to aid understanding. This may educate other personnel not involved in the fuelling of the potential hazards. Also the Ex sign should be used as this is common throughout industry. The Ex signage could be present on the fuelling equipment (i.e. refueller, dispenser, tanker) as the zones are only present during fuelling.

It is impractical to erect signage at points of entry on an apron where entry can be from numerous directions, employers should be able to demonstrate that they have taken equally effective means to alert people to location where an explosive atmosphere may occur and that special precautions are required for entry. This could be using marking on the fuelling apron to highlight the zones around wing vents for example. This would be difficult giving the varying nature of aircraft design. Therefore portable markings may be more appropriate, but time consuming to move in and out of position.

Due to the impracticalities of local signage, improving training and increasing awareness of airport apron personnel on the hazards associated with aircraft fuelling may be a more effective way to inform people of the locations of potentially explosive atmospheres.

Prior to the EI research report there was little information for flight apron operators with regards to HAC. There are a number of documents providing fuelling area/ zones for aircraft fuelling within CAP 74 which has now been withdrawn but are still used by some in industry. These fuelling areas/ zones are not applicable for HAC and have not been determined with DSEAR in mind. A fuelling area defines the distance from which fuelling equipment and aircraft fuel tank vents should be separated from buildings and is taken as 15 metres. A fuelling zone is taken as an area extending not less than 6 metres radially from the filling and venting points on the aircraft and fuelling equipment. It does not go as far as to say that ignition sources should be excluded from these areas/ zones but the CAA define a fuelling zone as qualifying as a Zone 0 or Zone 1, but again it is not advised that these are used for HAC. The HSE report AM5204 provides a diagram summarising these fuelling area/ zones and this is replicated in Figure 4.

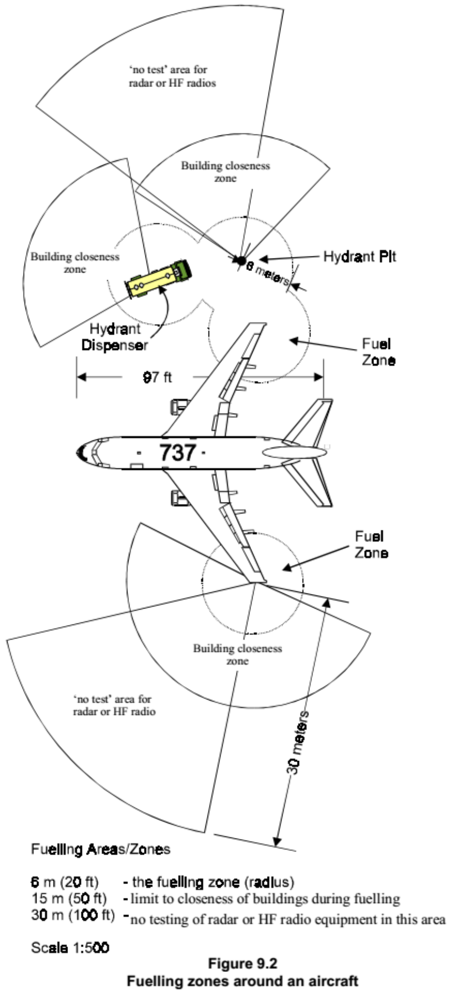

Figure 4 – Figure 9.2 from HSE AM5204

For those excluding ignition sources from this fuelling zone, they should have no issue with implementing the EI direct examples as the fuelling zone is of greater extent than any of the zones applied within the direct examples.

Once the zoned areas have been identified through HAC, airport operators must determine how they are going to control ignition sources within these zones and this must be recorded within their DSEAR assessment. A list of common ignition sources is listed below with any guidance from CAP 748 included:

- Hot surfaces;
    - Procedures should be established to prevent fuel ignition from other heat sources e.g. aircraft auxiliary power unit exhausts, overheated wheel brakes, jet efflux from other aircraft etc.
- Flames and hot gases (including hot particles);
- Mechanically generated sparks;
- Electrical source;
    - The use of any equipment with the potential to create or induce a source of ignition should be identified and excluded from any Fuelling Zone. Equipment maintenance, repairs, and testing procedures, including the operation of switches, radios and other devices, with the potential to create a source of ignition within the Fuelling Zone, should be deferred until fuelling has finished.
- Stray electric currents, cathodic corrosion protection;
- Static electricity;
    - Licensees should be aware that a spark of sufficient intensity to ignite fuel vapour may be produced by the discharge of electrostatic energy (static) created either from the movement of the fuel in the aircraft tank during the fuelling process, or its accumulation on the surface of aircraft or vehicles.

- Lightning;
- Radio frequency (RF) electromagnetic waves from 104 Hz to 3 1012 Hz;
- Electromagnetic waves including optical radiation from $3x10^{11}$ Hz to $3x10^{15}$ Hz;
- Ionizing radiation;
- Ultrasonics;
- Adiabatic compression and shock waves;
- Exothermic reactions, including self-ignition of dusts.

Further Research

The guidance provided in the EI report only considers the use of Jet A-1 fuel. A number of airports still store and dispense AvGas which is a more volatile fuel and therefore further research and guidance may be required to support these airports in determining their area classification. Elsewise these facilities may need to perform one off area classification for their fuelling operations.

Disclaimer

This paper and the work it describes were funded by the Energy Institute and conducted by RPS. Its content, including any opinions and/or conclusions expressed, are those of the author alone and do not necessarily reflect the Energy Institute or RPS policy.

References

1. EI Research Report, Aviation Fuelling Hazardous Area Classification, July 2017
2. AM5204 - Quantified Risk Assessment Of Aircraft Fuelling Operations, HSE 2000
3. Australian/New Zealand Standard™ Explosive atmospheres Part 10.1: Classification of areas— Explosive gas atmospheres (IEC 60079-10-1, Ed.1.0(2008) MOD
4. BGR 104, Explosionsschutz-Regeln (EX-RL), Sammlung technischer Regeln für das Vermeiden der Gefahren durch explosionsfähige Atmosphäre mit Beispielsammlung zur Einteilung explosionsgefährdeter bereiche in Zonen, Deutsche Gesetzliche Unfallversicherung, Juli 2008
5. BS EN 1127-1 - Explosive atmospheres - explosion prevention and protection, BSI, 2011, Annex B
6. BS EN 60079-20-1 Material characteristics for gas and vapour classification — Test methods and data, BSI 2010
7. EI Research Report - A qualitative assessment of electrostatic risks in jet fuel handling and distribution, Energy Institute, 2013
8. IATA Fuel Safety Zones harmonization (EI15-043) 2015
9. Investigation Into Explosion Hazards During The Handling Of Kerosene Jet-A1 In Tank Farms And During He Refuelling Of Aircraft, PTB-EX-2E, PTB 2008
10. Investigation into explosion hazards when handling kerosene Jet A-1 at aircraft, refuelling tankers and tank farms, PTB 2008
11. Investigation into explosion hazards when handling kerosene Jet A-1 at aircraft, refuelling tankers and tank farms, PTB 2008
12. Investigations into the formation and dispersion of explosive mixtures during the filling and discharging of aircraft refuelling tankers with kerosene (Jet A-1), PTB 2007
13. MH/15/75 Area Classification for Oil Mists - Final Report of a Joint Industry Project, HSL 2015
14. Mist Fires and Explosions, Santon, R. C. 2009
15. Model Code of Safe Practice Part 15, Area Classification for Installations Handling Flammable Fluids, 4th Edition, Energy Institute 2015
16. Prevention Of Fire And Explosion Risks On Plant For Refuelling Aircraft – Part 1 & 2, TUV 2011
17. Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2 API RECOMMENDED PRACTICE 505, API 2013
18. RR980 Generation of flammable mists from high flashpoint fluids: Literature review, HSL 2013
19. Shell MSDS, Product Code 002C0364 Shell, 2016

Figure 1 – Image Source Wiki Commons Author David Monniaux, 2005, License GNU Free Documentation license Version 1.2, https://commons.wikimedia.org/wiki/File:Jet_a1_truck_refueling_dsc04316.jpg

Figure 2 – Image source Wiki Commons user Barcex, 2008, License terms CC-BY-SA, https://commons.wikimedia.org/wiki/File:Airbus_A321-231_-_British_Airways_-_G-EUXH_-_EHAM_(5).jpg

Figure 3 – Image reference: Wiki Commons Author Jebulon, license creative Commons CCO 1.0 Universal Public Domain Dedication, https://commons.wikimedia.org/wiki/File:Fueling_plane_Athens.jpg