

Scientific principles of OME design assignment

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Submission date: 15-Dec-2022 06:19PM (UTC+0000)

Submission ID: 192597812

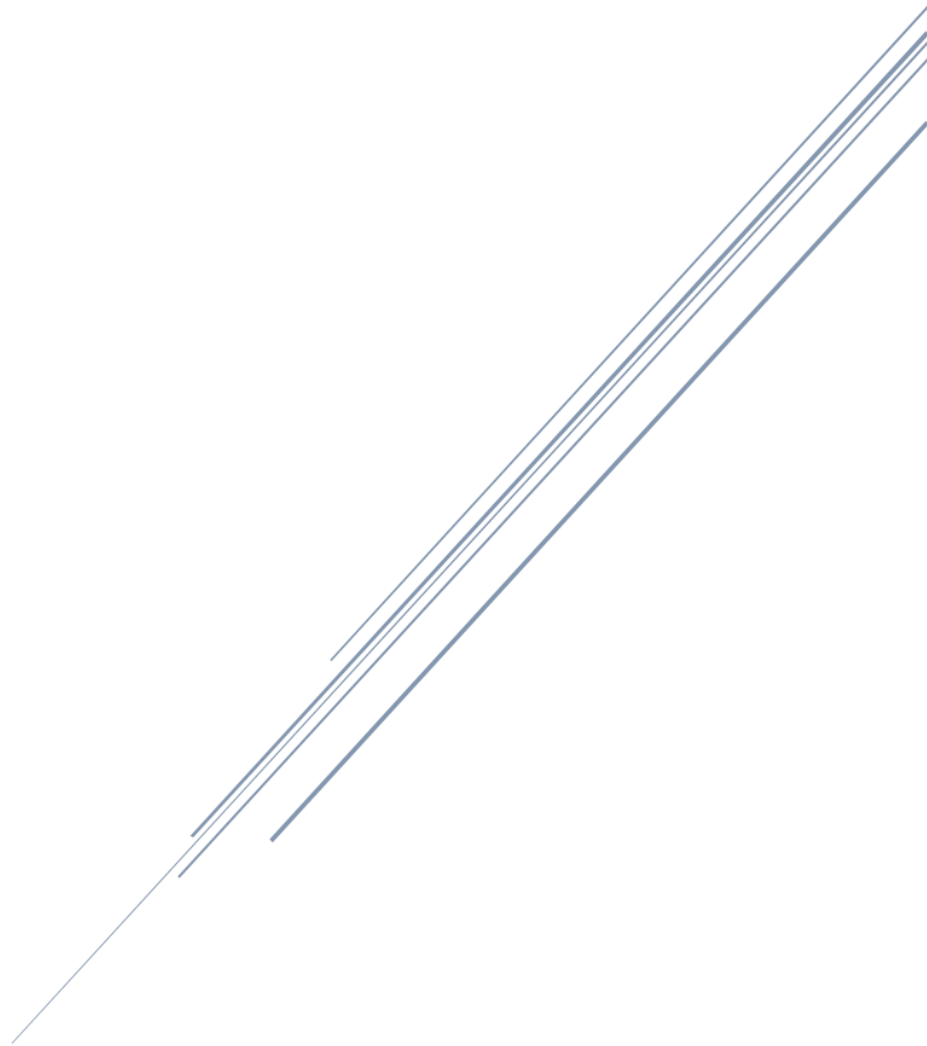
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Word count: 4117

Character count: 20935

Scientific Principles of OME Design Assignment (ACDA6008)

The theory and application of fuel-air explosions



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1. Abstract

The assignment will discuss the theory and application of fuel-air explosions, this requires that research be conducted and the findings reported on. The research showed that fuel air explosions work by mixing a fuel with the oxygen in the air and is then initiated which creates an explosion. The next thing that the assignment reports on is the history of fuel air explosions, this showed that they were first invented and used during the Second World War. They were also heavily used later in history during the Vietnam conflict by the American forces. Since their first invention there has been changes conducted to these devices making them perform more efficiently and effectively.

The assignment will then look at current use looking into the law around fuel air explosions and where they are being used. This showed that these types of system are being used in conjunction with similar systems currently in the conflict in Ukraine. The conventions that surround these devices is discussed and is a complex topic due to them not being banned from use but their use is heavily regulated. This will then move on to look at suitable targets it is used against and look at future applications it could be used for. This showed that there are many types of targets that this type of system can be used against and many potential future applications for this system.

The final thing that was to be researched and reported on was the difference between this type of explosive device and other weapon systems. This showed the main difference is that most conventional explosive devices contain their own oxidiser rather than relying on the oxygen in the air. This isn't true however for incendiary devices which do use oxygen from the air however they deflagrate rather than detonate. The assignment concludes by summarizing the information gathered and discusses the systems limiting factors, before finishing with all relevant sources used being referenced using the IEEE method.

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4. Introduction

The aim of this assignment as given in the assignment brief is to carry out an investigation into the theory and application of fuel air explosions with findings reported on. This was done by firstly researching how they work and the factors that affect them. As well as this information further research was carried out into their history as well as what current applications for them are and the conventions that surround them. Once this information was gathered, understood and reported upon further research went into looking at what they are currently used for, any potential future applications and the difference between this weapon systems compared with others. While carrying out research there is fortunately a wealth of information on these systems due to their use, testing and reporting on over the many years they have been used. All the information that was gained from this research has been referenced throughout with the additional reading that was carried out referenced in the bibliography at the end.

5. Fuel air explosion discussion

5.1. Theory

The principal theory behind the phenomena of a fuel air explosions is relatively simple, as the name suggests they comprise of a fuel which uses the air to cause an explosion. They work by dissipating the fuel through the air, it uses the oxygen in the atmosphere as an oxidiser for the explosion. When this mix of fuel and air described occurs it creates what is known as an explosive atmosphere. These explosive atmospheres are created from fuels such as dust, mist, vapour or flammable gases. When these types of fuels are mixed to the right levels with the oxygen in the air they only require an ignition source to be applied and it will cause an explosion. [1]

Explosive atmospheres occur in many different types of industries and is something that requires mitigations be put in place to protect against it. One mitigation that is used to stop it turning into a fuel air explosion with the potential to cause an extreme incident is to use water mist NaHCO_3 . This is used to reduce the flame temperature and slow down the rate of reaction propagating from the ignition source. [2]

In the defence industry these effects are something that are utilized as opposed to being mitigated against, hence why fuel air explosive devices were created and refined to achieve the most effective explosive characteristics. These systems are useful because when they explode although they do not have extremely high peak pressure, they have a high impulse. This impulse that occurs is what causes the damage to the target due to the energy that gets applied to it being over a longer period of time.

In the main these systems consist of a two-stage process with the first stage being the dispersion of the fuel through the air, this causes the required mix with the oxygen in the air. The second stage of the process is the detonation of the now mixed fuel with the air, this is a timed process for maximum efficiency allowing good dispersion and best mixture of the fuel. [3]

5.2. Effecting factors

In order for fuel air explosions to work effectively and efficiently creating the maximum explosive pressure there are many factors that affect their performance. One of these factors is the size of the droplet or dust that is used as a source of fuel. As well as the size of the droplets or dust it is also important to consider the speed and how it will be spread to ensure best dispersion pattern and most efficient mix. Another factor that effects how well the fuel is mixed with the oxygen in the air is the density of the air and therefore the

altitude it is used at. There are also environmental factors that effect it such as the weather and temperature where it is intended to be used. [4]

The temperature created by the initiator has a major effect on how the ignition propagates through the fuel. If a high ignition temperature is used it will increase the explosive pressure of the device and decrease the time for the reaction to occur. Other factors include the amount of fuel used, the fuel type that is going to be used and if any additives are being used. [5] One type of additive that has a major effect on the performance is the additive of metal dust, one common example is the use of aluminium dust which increase the impedance and heat of reaction further. [6]

5.3. History

It is likely that the first fuel air explosions that occurred were not something that was done intentionally and caused an incident or accident, likely due to an accidental explosive atmosphere being created and initiated. This can happen due to fuel mixing with the oxygen in the air and then when an ignition source such as a spark is presented it makes the reaction begin, this propagates to cause an explosion.

The first intentional fuel air explosion was during world war two by the German army, where they fired five rockets with propane gas followed by a detonating charge to ignite them. It was then used heavily again in the nineteen sixties by the United States during the Vietnam conflict. One of these early fuel air explosive devices created in the United States was patented and invented by Robert W Byrne in Missouri in 1970, it was described as to cause "destruction though synergetic effect of excessive heat, pressure" [7].

These systems have since been improved upon and progressed so that they perform more efficiently and have become more complex since their first use. As time moved on from the early fuel air explosive devices it become apparent that improvements could be made, this was due to problems encountered and lessons learnt. Some of the new requirements included the requirement for the sensitivity of the fuel be improved upon, improvement to their efficiency to maximise the potential damage, improve its life in service as well as the ability to store it safely while and remaining stable.

The initial devices like the ones previously described would have used a fuel like ethylene oxide this was changed due to the reasons described to instead use propylene oxide. The main reason for this particular change to the fuel source was due to problems that were encountered while they were held in stores. Other benefits to the change included an increase to the heat of combustion and the effects of the blast wave. [3]

5.4. Current application and conventions

As can be seen online and on the news these types of systems are currently being used in the conflict that is currently ongoing in Ukraine, as well as other recent conflicts. These weapon systems have often been referred to as the most devastating non-nuclear weapon system that have been developed. For this reason there is regulatory and legal limitations put in place around fuel air explosive devices use. The regulations around these systems is complicated and they are not explicitly banned under The Hague and Geneva Conventions. The Geneva Convention is in place to protect victims of conflict by doing things such as prohibiting the use of weapon systems such as biological and chemical [8]. The Hague is in place to limit and regulate the methods of warfare that are used during a conflict. [9]

As stated although they are not specifically banned it does depend on the manner that the system is used in. They are regulated by the Geneva Convention so that they do not cause harm to civilians, this means

they cannot be used against military targets where they have the potential to cause harm to civilians or directly on civilians [10]. This is due to the way in which they work having the potential to cause Asphyxiation to personnel nearby, due to them removing oxygen from the air for the reaction to occur. This is where death could be caused by depriving someone of oxygen.

There are other conventions other than these main two which also control the use of these weapon systems. The first one of these is the Environmental Modification Convention also known as ENMOD which was signed after the devastating effect the Vietnam War had. This prohibits the use of the environment as a weapon, this could apply to these systems due to them requiring oxygen from the air to function [11].

Another control for these systems is the United Nations Convention on Certain Conventional Weapons (UNOD). This convention prohibits and restricts weapon systems which their effects are indiscriminate and have the potential to cause excessive harm. This convention means that it also controls their use against civilians, with it also controlling their use against some structures [12] .

As can be seen from what is described above there are some limiting circumstances where these systems can be used due to no clear defining ban for them. This is why these types of system are still being used during recent and current ongoing conflict due to this grey area and the deadly effects they have.

5.5. Suitable targets

Fuel air explosive devices when designed and made correctly are very effective and efficient at destroying certain targets. These systems are currently used in the military environment to do things such as structural damage, cause harm to personnel and for counter-mobility obstacles. One example of the kind of targets that they are used against is caves and tunnel systems where equipment is kept and personnel use for hiding in. This is due to them being a confined space with limited oxygen supply and carry the blast wave effectively through the tunnel systems. This is effective due to the oxygen that is present being used for the explosive reactions as well as the blast wave and impulse causing damage.

The reason that these systems are so effective against the targets described is due to the propagation of blast waves in air. Looking at the example of the damage to the structure it cause damage due to the way the shock wave travels around a through the structure. The blast wave breaks windows with some potential structural damage then the blast wave forces the floors inside the structure upwards. As the blast wave comes over the top of the structure it will push with a downwards force upon it. As it passes the structure a pressure will be applied to the rear of the structure and cause further damage to it. These forces that are applied can cause severe structural damage or cause a collapse of the structure.

These devices are also very effective and often used in a high populated area due to their high lethality against personnel. The reason these systems have such a deadly effect against personnel is due to the blast, heat and asphyxiation that they cause. The effects of these systems on personal are the initial blast pressure wave causes death or blast injuries to individual due to the high impulse of these systems. The blast pressure also has the ability to cause internal harm to pulmonary systems, cardiovascular systems, gastrointestinal systems as well as central nervous systems. These systems also have an effect on the auditory system due to the noise produced from the explosion as well causing burns from the heat produced. [13]

5.6. Potential future application

There are many different types of potential future applications for this type of system, the first one of these is using this type of system for clearing unexploded mines. This could be a very useful method for carrying out safe clearance of a large area that contains unexploded mines. The reason that this would be so useful is due to it being a safe way of making a large area with potentially dangerous devices present safe to use. It would work by using a remote device to apply a mist or liquid to cover the desired area with an ignition source then applied to it causing an explosion. This explosion should then cause any explosive devices buried underground or hidden to initiate thus rendering the area safe for use.

Another potential future application for fuel air explosions is to use them for rendering a tank inoperable in the battlefield. Usually these types of devices would not be used due to them not being able to destroy a tank or cause severe damage to the personnel inside. Given modern tank designs with the many different types of sensors and optics mounted externally these could be rendered unusable thus making the tank unusable. Many of the modern tanks now also have explosive reactive armour fitted or non-explosive reactive armour fitted, these will activate if the fuel air explosive device hits the tank. This initiation of the reactive armour will not only render the tank easier to attack for other weapon systems, but also having an impact on the crew inside the tank rendering them inoperable for some time.

Investigation into better performance and efficiency of fuel air explosions are currently looking at making the two stage process for dispersion and ignition described previously one single step. This could be done by using a catalyst that reacts with the oxygen in the air, so as the catalyst ignites it will then ignite the fuel thus causing an explosion in one whole process. For this to work successfully it would require a consistent mixture of the fuel and catalyst be dispersed creating a vapour cloud which initiates consistently with the air. [3]

Looking at the future with a growing emphasis on sustainability and the environment, renewable sources of explosive fuels would be a preferred option. This could give substantial benefit to the use of fuel air explosive devices due to the potential fuels that could be used that have come from a renewable source. One example of this type of system is to use hydrogen and ammonia that has come from a renewable source as a fuel source for the system. This can be done by using electric that has come from a renewable source to gain the hydrogen from water and the ammonia can be gained from decomposing organic matter. [14] This makes the whole process sustainable and it has much less of an impact on the environment from the manufacturing process.

5.7. Comparison of fuel air explosives with high explosive device, incendiary and thermobaric

Conventional high explosive devices are what is primarily used on the battlefield currently, examples of the sort of explosives that would be found are trinitro-toluene (TNT) and hexahydro-trinitro-triazine (RDX). There are many differences between how a fuel-air explosion compares with these conventional high explosive devices. The first one of these differences is that fuel air explosive devices have higher thermal effects compared with high explosive devices. Another is that high explosive devices contain their own oxygen source within the system.

One other key difference is the peak pressure in fuel air explosives is lower than high explosives but goes on for a longer period of time, this can be seen in the graph below in figure 1. The first portion of this graph shows the high pressure shock wave that is produced by the high explosive immediately as it is detonated.

When it hits the point of THE shown on the graph the high explosive has now got a negative pressure whereas the thermobaric explosion still remains positive. It is not until the point shown as tTBE when the thermobaric system becomes negative, at this point the high explosive is now positive again. The combustion zone for the thermobaric system is much larger than high explosive. The thermobaric peak pressure is lower but its time is longer giving it a bigger surface area under the graph making the pulse duration longer. This gives it a higher level of impulse which reduces the chance of structures and personnel surviving the blast due to the force applied to them. Although the graph below shows a thermobaric system the effects are very similar and is used for reference purposes only. The below graph in figure 1 was gained from an article on Explosive Weapons in Populated Areas by the Armament Research Services in Perth in 2016. [15]

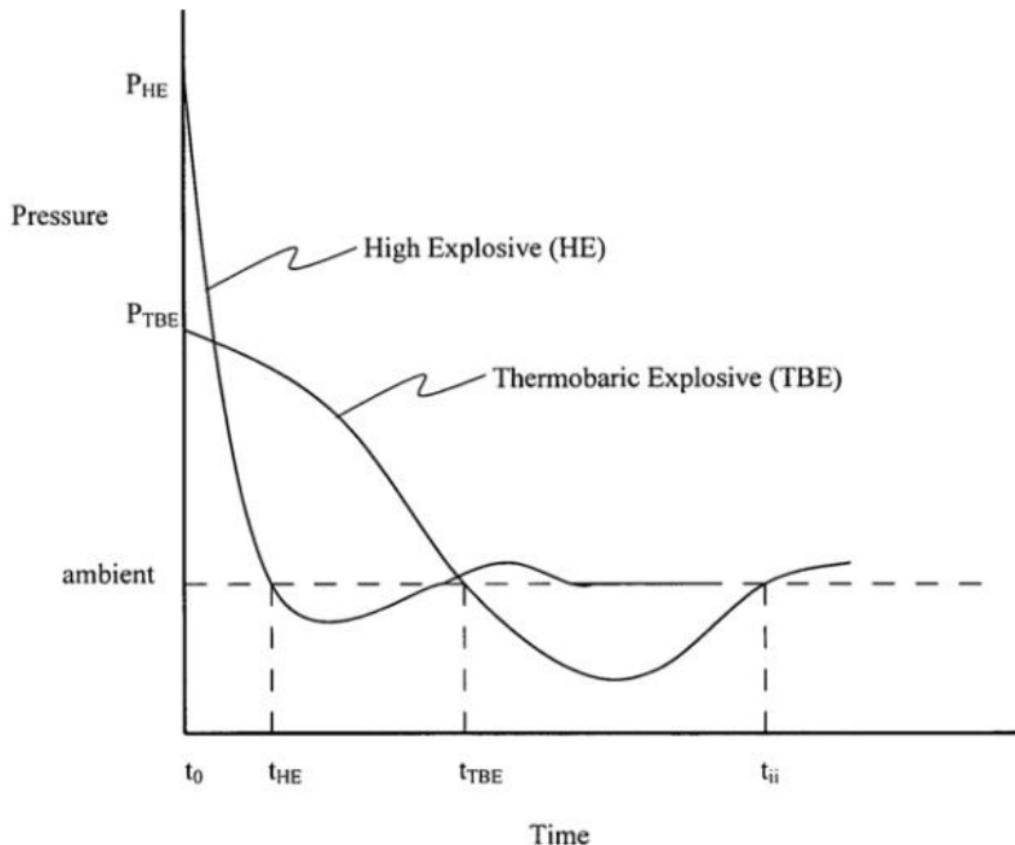


Figure 1- Graph of pressure against time comparing high explosive and thermobaric explosions [15]

Incendiary weapon systems are another example of a system which uses a fuel and the oxygen in the air to cause a reaction. These types of systems were very heavily used in the past, one example being the Vietnam conflict. Examples of the types of fuel that are used in these types of devices are white phosphorous, napalm and thermite. The difference between incendiary weapons and fuel air explosive devices is that they deflagrate as opposed to detonate, meaning that they burn as opposed to explode. A fuel air explosion will produce almost instant damage from high heat and blast whereas incendiary devices will produce fire to cause damage through burning. [16]

There is a close relation between the way in which fuel air explosive devices and thermobaric systems function. They both use fuel and oxygen to create an explosive atmosphere which is then ignited to create

an explosion. However there is one key difference between these two types of system which is that thermobaric systems contain an oxidiser element giving them their own source of oxygen within the system. This source of oxygen aids in propagation of the explosion rather than relying solely on the oxygen that is in the atmosphere entirely like a fuel air explosion does. [17]

6. Conclusion

As discussed previously there are limiting factors associated with these systems, one of these is the altitude at which it can be used at. This is due to the density of air as altitude increases reduces, this means this system would be unsuitable to use against aircraft effectively. Another limiting factor is the weather for example water from rain or snow mixing with the fuel dispersion reduces their performance. Another effect the weather has is the wind makes it difficult to hold the fuel in one place and difficult to stop it drifting. Another limiting factor of these systems is that they cannot be used under water due to there being no oxygen elements present that are free to react.

Although these systems do have limiting factors as well as legislation that heavily governs their use, they are still highly effective and useful systems. As is described they only use two stage system, dispersion of fuel and then initiation using oxygen from the air which makes them very simple. They have been used widely in previous historical conflicts as well as more current conflicts and have proven their effectiveness during them. These devices have a proven record against targets such as personnel, structural and for counter-mobility. There is exciting future work that could be conducted to investigate other applications for these systems as well as further refinement. There are other weapon systems that are used during conflict however these systems have a place alongside them, due to their unique characteristics as well as their current and future capabilities.

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GRADEMARK REPORT

FINAL GRADE

55/100

GENERAL COMMENTS

Instructor

In the assignment, you demonstrated a reasonable understanding of the theory and application of FAE. However, the effect of blast on structures could have been better written (page 5), so please do some more reading/study on this concept.

Your sentence construction was somewhat erratic and could have been improved throughout. Consider using a colleague to conduct a final peer review. This detracted significantly from the readability and understanding of the submission.

Page 3 would have benefitted from listing the factors 'affecting' (not effecting) performance and supporting each with a statement.

In the potential future uses section, there are some historic examples that you could have referred to. For example, Israel has used FAE systems to clear minefields in the past.

Did you consider why conventional solid explosives are used in preference to FAE in modern warfare? You compare/contrast, but what about logistics, reliability, ergonomics etc?

Finally, there were several areas where additional information, diagrams or tables could have supported your examples. I think technical authoring will help you overcome some of my comments/observations and is something we can work together on as you move towards your work-based project.

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