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Research Article

Phenomenon of Deflagration to Detonation in Pulse Detonation Engine

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Abstract

A self-sustained wave of chemical reaction propagating through a gaseous explosive mixture is one of the most basic manifestations of gaseous combustion and hence the central issue of interest in combustion science. The phenomenon in which the wave of flame front travels at sub-sonic velocity due to combustion is called Deflagaration while the phenomenon in which the propagation of flame front takes place at high speed due to sudden auto ignition in the combustion chamber is called Detonation. This both terms Deflagration and Detonation are of great interest for researchers as both can produce energy in efficient way . A large number of theoretical , Experimental study has taken place in order to understand basic mechanism of transition from Deflagration to Detonation.

Keywords: *DDT, Detonation, Deflagration, Flame Propagation*

1. Introduction

Many of the conventional propulsion engines have deflagration mode of combustion. The new way and most interesting area of pulse jet development is the Pulse Detonation Engine (PDE). The PDE and conventional propulsion engines has one fundamental difference that it detonates the mixture of air/fuel than just allowing it to simply deflagrate that is just burn vigorously. When we have to produce more thrust a lot of pressure is required to generate into the engine that is why researchers are trying to build a Pulse Detonation Engine which will detonate the fuel charge than just burn it in a deflagrating reaction .

A pulse detonation engine is a propulsion system which uses detonation waves for combustion of mixture of fuel and oxidizer .The engine is pumped because the fuel in the engine is renewed after every Detonation cycle. If we consider an Ideal PDE it has more efficiency than any other turbojet and turbofan because the compression taken place due to detonation is high and the Temperature is raised till its auto ignition. The Jet Engines work on deflagration of fuel which is rapid but works at sub sonic speed. The new concept to run Jet Engines is detonation which have supersonic detonation of fuel. Constant volume combustion is efficient than open-cycle designs like gas turbines, which leads to greater fuel efficiency. This should help smooth out the otherwise high vibration pulsejet engine; many small pulses will create less volume than a smaller number of larger pulses for the same net thrust. Unfortunately, detonations are many times louder than deflagrations. The major difficulty with a pulse-detonation engine is starting the detonation. While it is possible to start a detonation directly with a large spark, the amount of energy input is very large and is not practical for an engine. The typical solution is to use a deflagration-to-detonation transition (DDT) that is, start a high-energy deflagration, and have it accelerate down a tube to the point where it becomes fast enough to become a detonation. The detonation can be sent around a circle and valves ensure that only the highest peak power can leak into exhaust.

2. Detonation vs Deflagration

Deflagration is what happens when you burn a mixture of air and fuel at reasonably low pressure. Deflagration is a relatively gentle process which is simply the rapid burning the fuel. When we cause an air/fuel mixture to deflagrate in a semi-enclosed space (such as a pulsejet or auto-engine) then pressure is generated and that pressure can be harnessed to perform some work, e.g. create thrust or turn a crankshaft. Deflagration has a subsonic velocity, typically 1 m/s and pressure range is 7 to 10 bar starting at ambient pressure. Detonation has a Supersonic velocity. In detonation, high pressure shock front is ahead of the reaction zone. There is Adiabatic compression in detonative combustion that is gas auto ignites when its auto ignition temperature is achieved. Average pressure achieved in detonative combustion is 15 to 19 bars (lean), combustion pressure ranges from 25 bar to 30 bar (stoichiometric) Typical peak pressure attained in a detonative combustion is up to 50 bar Typical velocity achieved in detonation is approximately 1,500 to 3,500 m/s. In

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detonative combustion Flame temperature is approximately 1,600 K (lean) to 2,300 K (stoichiometric).

Detonation is more powerful reaction of mixture of air/fuel which result in a rapid reaction that the pressure wave travel at very high speed .As deflagration reaction is simple combustion reaction of fuel and air mixture while in detonation there are violent explosions due to which they create high pressure. So if we want to create an Engine which produce more power we have to create an engine which create more high pressure so we need to move towards Pulse Detonation Engine by using phenomenon of Detonation. Detonation is initiated repeatedly at either the closed or the openend of a detonation chamber that is filled with a premixed fuel–air mixture. A one-dimensional planar detonation isinitiated near the closed end of the detonation chamber and travel sat the C–J velocity toward the open end. A set of rarefaction waves trail the detonation wave to reduce the velocity to zero at the closed end of the tube. When the planar detonation wave exits the chamber, another set of expansion waves is generated that travels toward the closed end. These waves evacuate the burned detonation products resulting in a cool, empty chamber that is ready to be filled with afresh fuel–air mixture. The entire cycle repeats, resulting in a periodic high-pressure zone near the closed end of the chamber. The integrated effect of this high pressure over the closed end (representing a thrust wall) produces thrust.

3. Deflagration to Detonation reaction

The one way for starting detonation process is pressure. If we compress the mixture of fuel and air it is easier to start detonation. But the Pulse jet Engines do not produce high pressure in order to start Detonation reaction. Firstly the mixture of fuel and air is introduced into the combustion chamber then immediately after it a highly volatile fuel like hydrogen is introduced in trigger chamber at the close end of the pipe. Now the ignition of this mixture is initiated by a very powerful electric discharge and the detonated mixed is allowed to move through properly designed passages so that it create high turbulence.

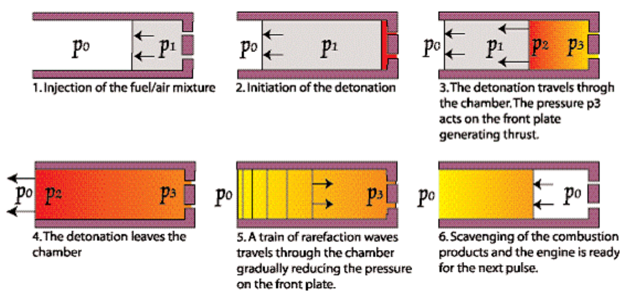


Fig.1. Pulse Detonation Engine Cycle

The tube used into this process is called Detonation to Deflagration tube and the function of that tube is to burn the mixture of fuel and air and volatile fluid to get supersonic shockwave. Once this mixture is detonated it is allowed to hit the main fuel and air mixture which is in secondary chamber of the Engine. Because of supersonic speed of this wave front the mixture of fuel and air gets compressed though it has an open end as a result the mixture gets highly compressed and gets the Energy from highly intense heat of shock wave.

3.1 Transition from Deflagration to Detonation

The Detonation reaction cannot be achieved as it requires huge pressure and also the results of detonation are devastating. So Detonation to Deflagration reaction or transition means using combustion reaction of ignitable mixture of Air and Flammable gas(Deflagration reaction) for initiation of highly powerful detonation. The deflagration reaction moves with sub sonic flame propagation velocity which is usually 100 m/s and at low pressure of 0.5 bar .The mechanism of combustion propagation is of flame front that moves forward through gas mixture by diffusion of heat and mass . At beginning deglagration might be just flash fire .

Detonation travels with super sonic flame front velocity which is usually 2000 m/s and with high pressure of 20 bar .The important function of mechanism of combustion propagation is that the it compress the unburnt gases present ahead of the flame front and raise its temperature above its auto ignition temperature .So the transition from deflagration to detonation takes place from low velocity and low pressure to high velocity and high pressure and using property of auto ignition by providing it temperature above its auto ignition temperature.

3.2 Pre Detonation

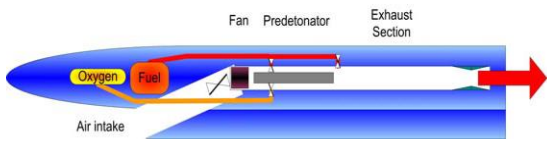


Fig. 2. Pulse Jet Engine with Detonator

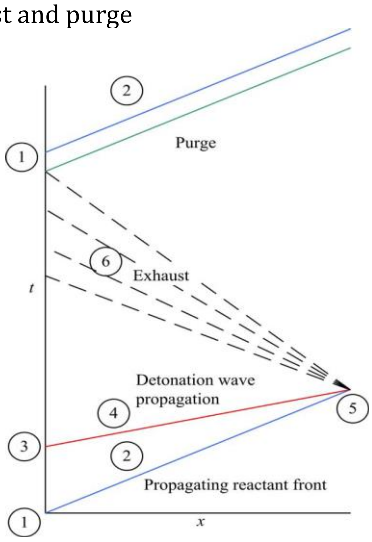
Pre-detonation concept is used for overcoming the difficulty of initiation of detonation for liquid fuels in a following manner.

- Fresh mixture of air-fuel charge is introduced into suction manifold
- Small amount of detonative mixture of a very volatile fuel and an oxidizer are injected into a primary combustion chamber which are open at one end and close at another end
- The Combustible mixture is initiated by very powerful electric discharge.

- Detonating pressure wave creates the high level of turbulence in the burning mixture which then creates a supersonic shockwave
- Once it detonates, the small charge in the primary chamber creates a very powerful shockwave which hits the bulky air/fuel charge in the engine's secondary combustion chamber.
- Combustion is pulsed because the mixture must be renewed in the combustion chamber between each detonation wave initiated by an ignition source.

4. Basic PDE Cycle

- The chamber is at Ambient Condition
- The Propellants are introduced from closed ends
- Variation sidewall injection
- The ignition is taken from closed End
- Wave propagation and transition in tube
- The Wave leaves the tube
- Correct timing ensures that the wave reache to exit at the same time as propellants
- Exhaust and purge



4. Critical Issues

1) Potentially high-payoff aerospace propulsion system.
2) Start of the detonation.
3) High frequency by which the detonations have to be repeated.
4) Optimization of Design.
5) Induction of Air.
6) Mixing and Injection of fuel and air.
7) Coupling with external flow.
8) Immediate detonation after ignition.
9) High altitude and space applications.
10) Engine and vehicle integration.

5. Case Study

The deflagration-to-detonation transition (DDT) has been studied in prepared columns of granular secondary explosive. The secondary explosives 2-(5-cyanotetrazolato) pentammine cobalt (III) perchlorate (CP) and pentaerythritoltetranitrate (PETN) were chosen for the study due to their known propensity to undergo DDT within a few millimeters of ignition. Confinement of CP columns within polycarbonate and PETN within metallic confinement fitted with slit windows allowed direct high-speed streak photography of the events. Deflagration and detonation velocities and the run-to-detonation lengths were measured as a function of charge pressed density. Ignition of the explosive column was attained thermally through a copper barrier with a gasless pyrotechnic. Deflagration and detonation velocities were seen to depend strongly upon pressed density with both explosives. There appeared to be a maximum density conducive to DDT with both explosives but no minimum with CP. Studies of DDT continue to have interest for the safe storage and use of reactive materials, and for the development of a detonator based on a secondary explosive.

Conclusion

In the following report we studied how detonation can be achieved smoothly because of following difficulties. Initially the Deflagration Process do not result in high energy or high power as it runs at low pressure and also have its flame front which travel at low velocity . On the other hand by using the Phenomenon of Detonation we can get high Energy in less time. But due to Difficulties in detonation it cannot be used effectively so research are carried on in order to have stable detonation process.

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