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RESEARCH ARTICLE

PULSE DETONATION ENGINE: THE ADAVANCED PROPULSION TECHNOLOGY (MILITARY AND SPACE APPLICATIONS)

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ABSTRACT

In this paper my main emphasis on the Pulse Detonation Engine (PDE). Pulse detonation engine (PDE) is an air-breathing combustion engine in which detonations are triggered at high frequencies through simultaneously burning and accelerating the fuel-air mixture. Pulse detonation Engine is next generation technology which will change the present aerospace propulsion techniques both in military and space flights. Aircraft will cross continents and oceans at higher speeds and efficiencies. Spacecraft launching with higher safety factors and lower costs. Military aircrafts will operate in many flight conditions with increased performance. This is the potential for Pulse Detonation Engine (PDE) technology; it has the capability to revolutionize the aviation industry. Also change the way rockets and missiles are launched. We will also discuss about the how pulse detonation engine revolutionize the future hypersonic and missile or spacecraft technology.

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INTRODUCTION

A pulse detonation engine (PDE) is a type of propulsion system that uses detonation waves to combust the fuel and oxidizer mixture. The engine is pulsed because the mixture must be renewed in the combustion chamber between each detonation wave and the next. Theoretically, a PDE can operate from subsonic up to a hypersonic flight speed of roughly Mach 5. An ideal PDE design can have a thermodynamic efficiency higher than other designs like turbojets and turbofans because a detonation wave rapidly compresses the mixture and adds heat at constant Volume. The main differences between the pulse detonation engine and the conventional internal combustion engine is that in the pulse detonation engine the combustion chamber is open and no moving parts are used to compress the mixture before ignition and no shaft work is extracted. Pulse detonation will develop an efficient engine that is primarily used for high-speeds (potentially Mach* 5), as well as high-altitudes. The basic concept behind the technology is to detonate rather than deflagrate the fuel. The detonation of fuel results in immense pressure, which in turn is used as thrust.

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Cyclic Analysis of PDE

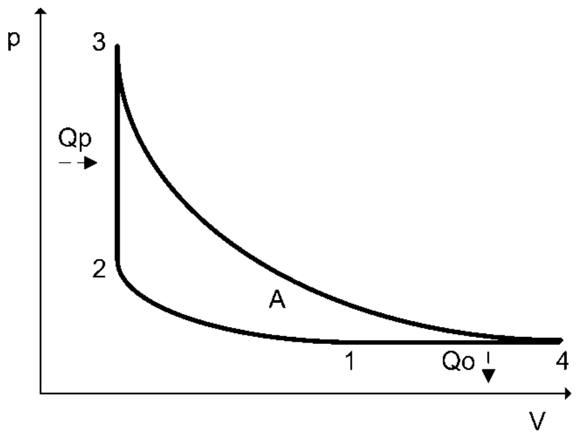
In pulse detonation Engine, thermodynamic analysis is done by Humphrey cycle. The humphrey cycle consists of four processes are as.

1. Reversible, adiabatic (isentropic) compression of the incoming gas. During this step incoming gas is compressed, usually by turbomachinery. Stagnation pressure and temperature increase because of the work done on the gas by the compressor. Entropy is unchanged. Static pressure and density of the gas increase.

2. Constant-volume heat addition. In this step, heat is added while the gas is kept at constant volume. In most cases, Humphrey-cycle engines are considered open cycles (meaning that air flows through continuously), so this means that the specific volume (or density) remains constant throughout the heat addition process. Heat is usually added by combustion.

3. Reversible, adiabatic (isentropic) expansion of the gas. During this step incoming gas is expanded, usually by turbomachinery. Stagnation pressure and temperature decrease because of the work extracted from the gas by the turbine. Entropy is unchanged. Static pressure and density of the gas decrease.

4. Constant-pressure heat rejection. In this step, heat is removed from the working fluid while the fluid remains at constant pressure. In open-cycle engines this process usually represents expulsion of the gas from the engine, where it quickly equalizes to ambient pressure and slowly loses heat to the atmosphere, which is considered to be an infinitely large reservoir for heat storage, with constant pressure and temperature.



$$\eta_H = 1 - \gamma \frac{T_2}{T_3} \frac{\left(\frac{T_4}{T_3}\right)^{1/\gamma} - 1}{\frac{T_4}{T_3} - 1}$$

Basic working of PDE

A pulse detonation engine is an unsteady propulsive device that contains four major steps per cycle. These steps appear in The first step consists of filling a combustion chamber with combustible gases and initiating detonation. In the second step, the detonation wave propagates to the open end of the tube followed by the Taylor wave. Taylor wave is an unsteady expansion wave propagating towards the closed end of the tube. The Pressure, Temperature and Flow velocity reduces due to this Taylor Wave and this wave is responsible to thwart the flow near the closed end of tube. The third step begins with the reflection of the expansion wave off the interface. This reflected expansion immediately interacts with the Taylor wave, while the products begin to exhaust the tube. The fourth step consists of the first characteristic of the reflected expansion reaching the front wall of the tube thus decreasing the pressure at this wall. Quasi-steady thrust levels can be achieved by repeating this cycle at relatively high frequency and/or using more than one combustion chamber operating out of phase.

Advantages of PDE Engine

Pulse detonation engines (PDE's) exhibit several performance advantages in comparison with current steady-deflagration jets. The inherent mechanical design simplicity of the PDE results in smaller packaging volumes and lower part counts, aiding in integration and maintenance. The thermodynamic efficiency of the pulse detonation cycle results in higher theoretical performance across a wide speed range.

1. Mechanical Design Simplicity

PDE was specifically designed to avoid the mechanical complexity of spinning compressors or other rotating machinery in its air-flow path. With the absence of a separate compression stage and the consolidation of the other stages of the detonation cycle into a single component, the PDE generally demonstrates a lower part count than other engine types. There is not rotating parts so it is very simple to design. The PDE's mechanical simplicity offers many benefits to propulsion systems. The lower part count makes for simpler maintenance procedures. It also contributes to an overall lighter engine, improving the thrust-to-mass ratio of equivalent engine systems.

2. Thermodynamic Efficiency

The thermodynamic efficiency of the pulse detonation process results in higher theoretical performance of the PDE across a wide range of flight conditions. Under ideal situations, the PDE has a theoretical performance advantage in both specific thrust and fuel consumption over conventional jet engines from the speed range of Mach 0-5. This is attributed to the near-constant-volume nature of the pulse detonation thermodynamic process. In addition to a performance advantage in low- to mid- speed ranges over conventional engines, the PDE also exhibits superior fuel economy. The extreme temperatures of the PDE reduce the presence of unburned hydrocarbons in the detonation cycle. Also, the speed at which the entire detonation takes place makes the thermodynamic cycle nearly constant-volume, improving fuel efficiency. The PDE engines are more efficient than gas turbines engine because the frontal area of pulse detonation engine is less than gas turbine engines.

3. Cost effectiveness

Due to mechanically simplicity, the pulse detonation engine is very economical as compared to turbojet and turboprop engines. There is no rotating parts (compressors and turbines). It will also helps to reduces the expenditure during the space launching.

Applications of Pulse detonation engine

The application of pure, combined-cycle and hybrid pulse detonation engines to continental and inter-continental flight.

Military Application of Pulse Detonation Engines

1. Hybrid Pulse Detonation

Pulse detonation engines are well-suited for combination with turbofan and turbojet engines. This hybrid combination can be applied not only to produce faster aircraft, but also to make them more efficient and environmentally friendly. In a conventional turbofan engine, combustion is used to turn a large fan, which drives air into and around the combustion chamber. The air travelling around the chamber mixes with the exhaust from the combustion chamber to provide the thrust. In a hybrid pulse detonation engine, the bypass air enters pulse detonation tubes that surround the standard combustion chamber. The tubes are then cyclically detonated; one detonates while the others fill with air or are primed with fuel. This combination promises to require simpler engine mechanisms and yield higher thrust with lower fuel consumption. Hybrid PDEs can also be used in military applications. A large number of modern fighter jets employ afterburner-equipped low-bypass turbofan or turbojet engines. In engines such as these, fuel is injected into the hot exhaust stream. The resulting combustion causes the exhaust gas to accelerate, and thus increase thrust. Although this process is an effective solution, it is not a fuel efficient solution. Hybrid PDEs will deliver the same thrust with less fuel consumption.

2. Pure Pulse Detonation

The applications of pure PDEs are primarily military, as they are light, easy to manufacture, and have higher performance around Mach 1 than current engine technologies. This makes them an ideal form of propulsion for missiles, unmanned vehicles, and other small-scale applications

3. Combined Cycle Pulse

Detonation Combined cycle pulse detonation engines may provide the most exciting possibilities for aviation. Adding a PDE to the flow path of a ramjet or scramjet engine would make an engine capable of operating efficiently as high as Mach 5. As scramjet engines are still themselves under development, the full scope of this combination and its applications are difficult to evaluate. However, these engines would seem initially suitable for high-altitude, high-speed aircraft. The PDE engine can be used in

- Cruise Missiles
- Supersonic Aircraft
- Hypersonic Missiles
- Hybrid Turbine-PDE
- UAV
- UCAV
- SSTO Launch Vehicles
- Precision Guided Munitions

Use of PDE in space flights

Pulse Detonations rocket engines.

Pulse detonation rocket engine technology is being developed for upper stages that boost satellites to higher orbits. The advanced propulsion technology could also be used for lunar and planetary landers and excursion vehicles that require throttle control for gentle landings. The engine operates on pulses, so controllers could dial in the frequency of the detonation in the "digital" engine to determine thrust. Pulse detonation rocket engines operate by injecting propellants into long cylinders that are open on one end and closed on the other. When gas fills a cylinder, an igniter—such as a spark plug—is activated. Fuel begins to burn and rapidly transitions to a detonation, or powered shock. The shock wave travels through the cylinder at 10 times the speed of sound, so combustion is completed before the gas has time to expand. The explosive pressure of the detonation pushes the exhaust out the open end of the cylinder, providing thrust to the vehicle. A major advantage is that pulse detonation rocket engines boost the fuel and oxidizer to extremely high pressure without a turbopump an expensive part of conventional rocket engines. In a typical rocket engine, complex turbopumps must push fuel and oxidizer into the engine chamber at an extremely high pressure of about 2,000 pounds per square inch or the fuel is blown back out. The pulse mode of pulse detonation rocket engines allows the fuel to be injected at a low pressure of about 200 pounds per square inch.

Conclusion

The pulse detonation engine is under development since 1940. this technology is able to change the present day propulsion technology. It will reduce the cost of space launched vehicle as well launching techniques. The PDE engine will be combined with turbofan/turbojet engines and work both as aircraft as well as spacecraft. Indian version of PDE engine is also under research and development. Surely that will help the entire mankind.

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