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The Effect of Ignition Parameters on the Combustion Characteristics of an Aviation Piston Engine

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Abstract

A cylinder combustion simulation model was established for a two-stroke aviation piston engine used in a small unmanned aerial vehicle. The influence of different ignition system parameters on the combustion process of aviation kerosene was studied using this model. The research results showed that under the working conditions of 5500 r/min and 50% throttle opening, as the ignition energy increased, the peak values of average cylinder pressure and average temperature increased, and the combustion duration shortened, The advance of the combustion center of gravity increases the tendency of the engine to knock. Under the same operating conditions, as the ignition timing advances, the peak values of average pressure and average temperature in the cylinder increase, gradually approaching the top dead center, and the tendency of engine detonation increases more significantly.

Keywords

Aircraft Piston Engines, Aviation Kerosene, Ignition, Combustion Characteristics, Knock

1. Introduction

The two-stroke piston engine has always dominated the field of medium and low-speed unmanned aerial vehicles due to its small size, convenient maintenance, simple structure, small rotational inertia, and high power to weight ratio [1] [2]. At present, gasoline is widely used in aviation piston engines. However, gasoline has a low flash point, high saturation vapor pressure, is prone to evaporation, and is highly explosive when exposed to open flames. Its safety is poor, and there are safety hazards in storage and transportation, which are severely restricted in the military field [3] [4]. Compared to gasoline, gasoline has the advantages of low melting point, high volatility temperature, high safety, and easy storage and transportation [5]. The US Department of Defense proposed a policy in the 1980s to use JP-8 (heavy oil) fuel as a single fuel for the battlefield [6], and continued to issue instructions in 2004 to strengthen this principle [6]. This measure reduces the possibility of accidental casualties caused by transportation and storage of military fuel. With the increasing recognition and attention of more and more countries, aviation piston engines fueled with heavy oil have broad application prospects.

The ignition piston engine is ignited by a spark plug, and the mixture is ignited by the spark plug, which then burns and releases heat. The expansion of the mixture in the cylinder works [7]. Scholars at home and abroad have studied the ignition parameters of aviation piston engines, and different ignition timing and energy have an impact on the power performance, emissions, and economy of spark ignition engines. At present, many piston engines use dual spark plug ignition technology when igniting. Spark plugs are installed on both sides of the central axis of the combustion chamber at equal intervals to accelerate flame propagation and improve combustion efficiency [8]. Chen Mingfei from Chongqing University conducted experimental research and found that when using dual spark plug ignition, the engine's power performance was improved, the cycle change rate was significantly reduced, and the engine's performance was improved [9]. Beitaixue *et al.* studied the effect of dual spark plug ignition on engine detonation. After using dual spark plug ignition, the combustion heat release rate was advanced, the flame propagation speed was accelerated, and the detonation tendency was reduced [10]. Scholars from Nanjing University of Aeronautics and Astronautics have explored the impact of ignition energy on engines [11]. Liu Guoman established a simulation model for the entire engine and combustion chamber to study the influence of different ignition advance angles on the combustion process of the engine. As the ignition advance angle increases, the cylinder CO and Soot displacements decrease, while the torque and power gradually increase [12]. Li Xin from Jilin University used simulation software to establish a computational model for the engine combustion chamber and studied the effect of ignition energy on the combustion process. The increase in ignition energy accelerated the formation of the flame nucleus and shortened the flame development period [13]. Liu Yirong established a three-dimensional simplified model and studied the influence of different ignition system parameters on the combustion process of the engine through simulation, preliminarily determining the optimal parameters of the ignition system [14]. Chang Cheng compared and studied the differences between kerosene and gasoline combustion processes, and quantitatively analyzed the effects of parameters such as ignition advance angle, initial core size, and mixture concentration on engine detonation combustion [15]. Zhang Ning explored the influence of ignition energy on engine combustion characteristics based on GT-Power and

Fluent, and effectively increased the ignition energy to increase the initial fire core size [16].

At present, there is relatively little research on the ignition parameters of aviation kerosene piston engines both domestically and internationally. This article will use GT Power and Fluent software to study the combustion characteristics of a small aviation piston engine burning aviation kerosene, and explore the influence of ignition energy and ignition time on the average cylinder pressure, average temperature, combustion heat release rate, and cumulative heat release of aviation piston engines burning heavy oil.

2. Establishment and Verification of Engine Model

A certain engine is a two-stroke piston engine, which serves as the power device for small unmanned aerial vehicles. It has small size, light weight, high power output, and simple structure. Based on the three-dimensional structural data of the engine, a shell model of the internal flow part of the engine was obtained using UG modeling software, as shown in **Figure 1**. The main structural parameters of the engine are shown in **Table 1**.

The engine workflow is as follows: fresh air enters the intake duct through the air filter and throttle valve, forms a mixture with the fuel sprayed by the injector, enters the crankcase through the spring valve, compresses and preheats in the crankcase, enters the cylinder through the scavenging passage, and the mixture

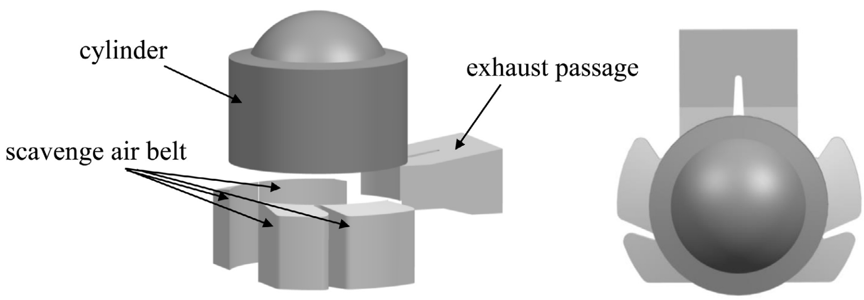


Figure 1. Shell diagram of the internal flow part of the engine.

Table 1. Main technical parameters of the engine.

Parameter	Numerical value
Engine type	Two stroke, spark plug point
Number of engine cylinders	2
Scavenge method	Loop scavenge
Cylinder diameter/mm	44
Stroke/mm	39.4
Displacement/cm^3	59.9 × 2
Compression ratio	11.2
Exhaust opening phase angle /˚CA	98
Opening phase angle of the scavenging port /˚CA	124

of fresh air and fuel vapor is ignited and burned using a spark plug. After combustion expansion, the exhaust gas produced by combustion is discharged from the exhaust duct. The engine workflow is shown in Figure 2.

Based on the corresponding data of the engine, a one-dimensional simulation model was established using GT-Power as shown in Figure 3.

The numerical simulation calculation process established in this article is that the exhaust duct is about to open, and the crankshaft angle is 98 ˚CA as the initial position for calculation. At this time, the initial and boundary conditions are calculated by GT-Power software as shown in Table 2. Other boundary conditions cannot be obtained due to conditions, so empirical parameters from reference literature are used for setting. The cylinder wall temperature is 550 k, the combustion chamber wall temperature is 650 k, and the piston top temperature

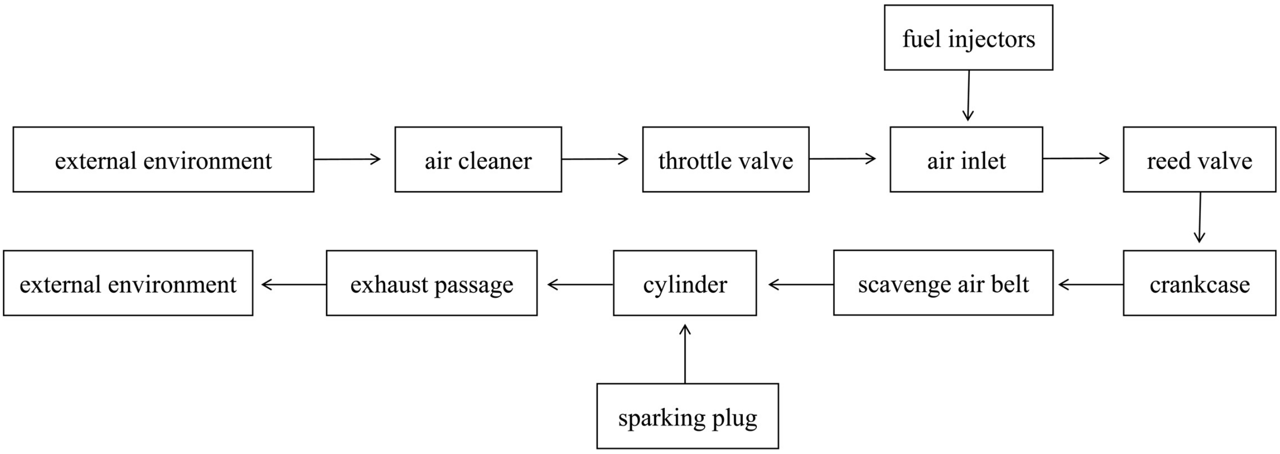


Figure 2. Engine workflow diagram.

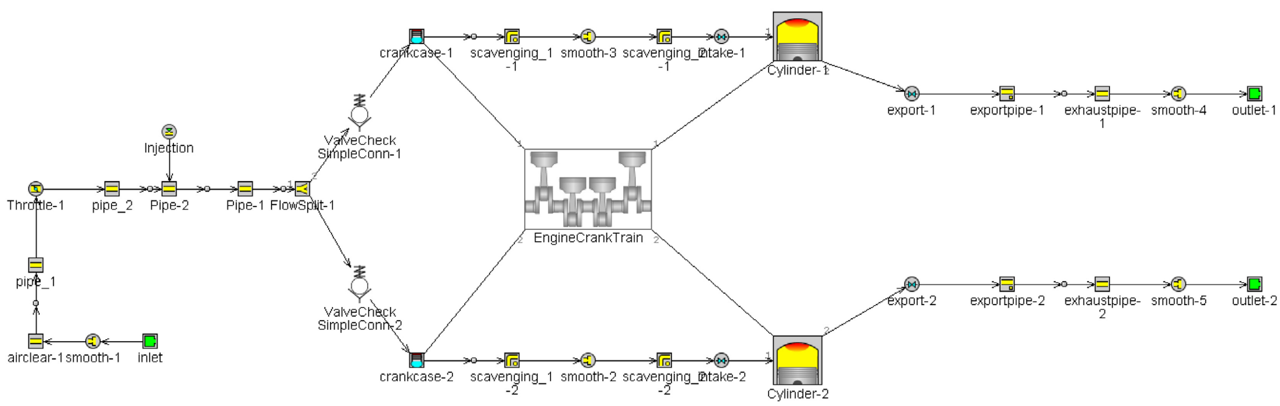


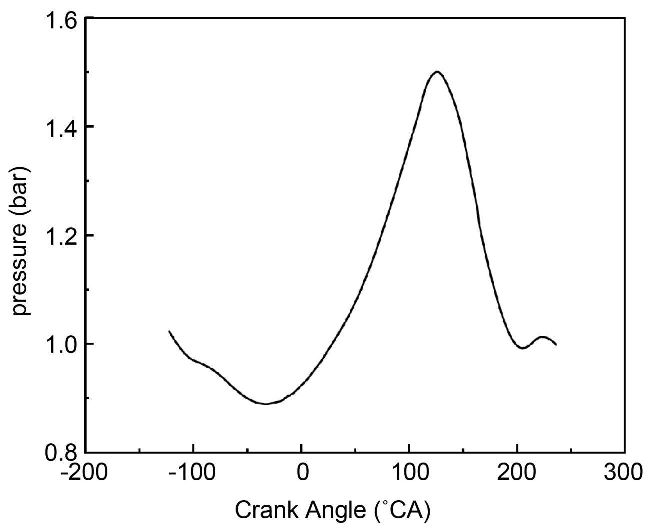
Figure 3. One dimensional simulation model of engine GT-Power.

Table 2. Calculate the initial conditions when the crankshaft.

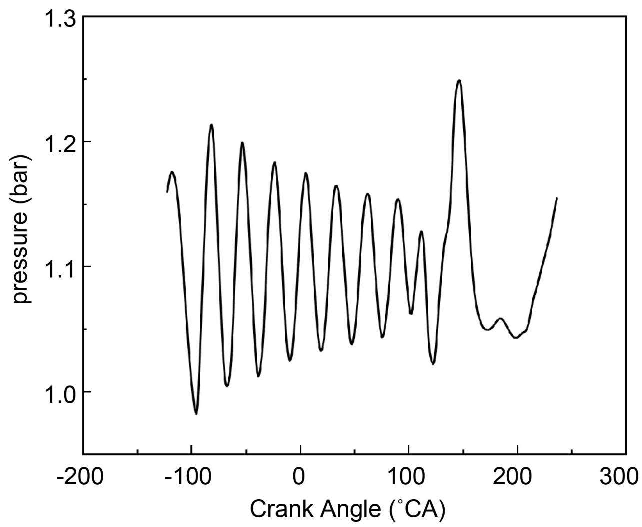
	Scavenge air belt	Cylinder	Exhaust passage
Temperature (K)	380	1473	475
Pressure (Mpa)	0.135	0.441	0.108

is 600 k Inlet wall temperature 360 K, exhaust wall temperature 580 K [17].

To reduce calculation time, this article omits the modeling of the crankcase in the simulation process, starting from the intake of the scavenging port. It is impossible to simulate the compression process inside the crankcase, and the flow in the engine duct is non-stationary. Simply giving the boundary values at the scavenging and exhaust ports makes it difficult to accurately predict the flow field characteristics in the cylinder, Therefore, this article will edit the boundary changes in the crankcase obtained from GT-Power with the variation of crankshaft angle and the boundary changes at the exhaust port into a Profile function, and import it into Fluent for compilation. The pressure changes at the intake and exhaust ports are shown in **Figure 4(a)** and **Figure 4(b)**.



(a)



(b)

Figure 4. Boundary conditions for the outlet of the scavenging and exhaust ports in CFD calculations. (a) Boundary conditions of the scavenging port; (b) Exhaust port boundary conditions.

For the simulation of the flow field in the engine cylinder, the most widely used $k-\varepsilon$ two-way model, the combustion model uses the Finite-Rate/Eddy-Dissipation model, which has the advantage of combining kinetic factors and turbulence factors, but is only suitable for single-step chemical reactions.

Import the geometric model of the internal flow part of the engine into ICEM for grid partitioning, using a hexahedral grid globally with grid sizes of 0.5 mm, 1 mm, and 2 mm. Divide the model into grids and use the obtained boundary conditions to perform cold simulation calculations on grids of 0.5 mm, 1 mm, and 2 mm. The simulation results are shown in **Figure 5**. From the figure, it can be seen that when the grid size is 0.5 mm and 1 mm, the calculation results are similar. The smaller the grid size, the longer the calculation time required. Therefore, a grid size of 1 mm is chosen. The total number of grids is 643,654, and the model grid is shown in **Figure 6**.

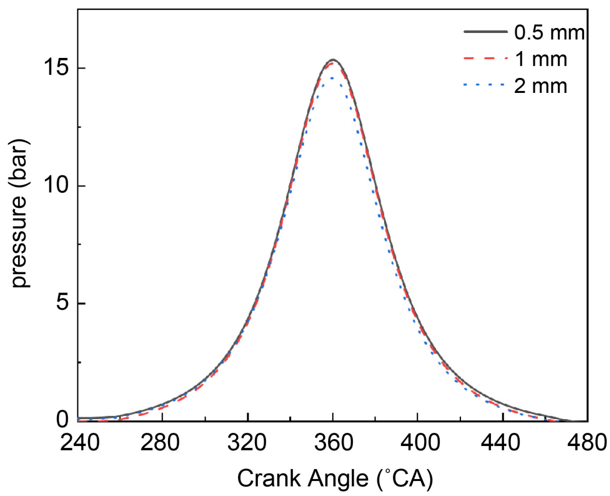


Figure 5. Comparison chart of different grid sizes.

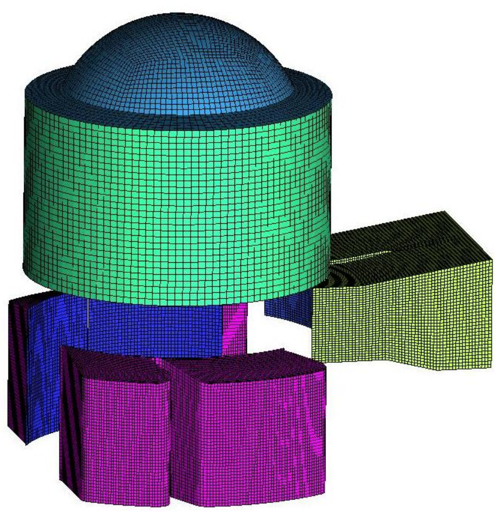


Figure 6. 3D CFD mesh model of engine.

After the model is established, it is necessary to ensure the accuracy of the model. The cylinder combustion pressure calculated by the one-dimensional simulation software GT-Power is compared and analyzed with the cylinder combustion pressure calculated by the CFD numerical simulation software Fluent. The engine speed of 5500 r/min, 50% throttle opening, ignition energy is 30mj, and the ignition time is 338 ˚CA working condition are selected, and the comparative simulation results are shown in **Figure 7**. From the curve of pressure variation with crankshaft angle in the graph, it can be seen that the trend of cylinder pressure variation between GT-Power simulation value and Fluent simulation value is basically consistent. The maximum pressure result error value of both is 1.51%, which is within the acceptable error range, indicating that the simulation model has a certain degree of reliability and can be used for subsequent simulation calculations.

3. Calculation Results and Analysis

3.1. The Influence of Ignition Energy on Combustion Characteristics

At a speed of 5500 r/min and a throttle opening of 50%, Ignition time 338 ˚CA, the influence of different ignition energies on the combustion process of two-stroke aviation piston engines was studied by calculating the ignition energies of 20 mj, 25 mj, 30 mj, 35 mj, and 40 mj, respectively.

Figures 8(a)-(d) respectively describe the variation of average pressure, average temperature, combustion heat release rate, and cumulative heat release in cylinders with different ignition energies as a function of crankshaft angle. As shown in the figure, increasing the ignition energy improves the combustion state in the cylinder; Shortening of combustion duration; The average pressure

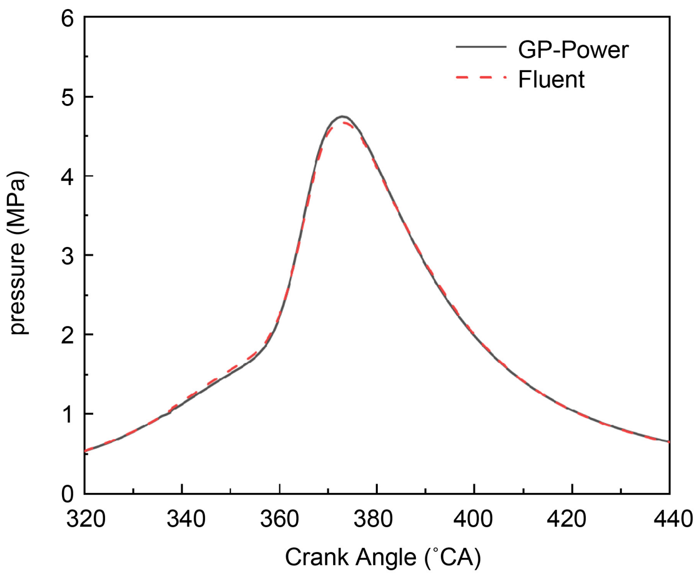


Figure 7. Comparison of simulation results of average cylinder pressure.

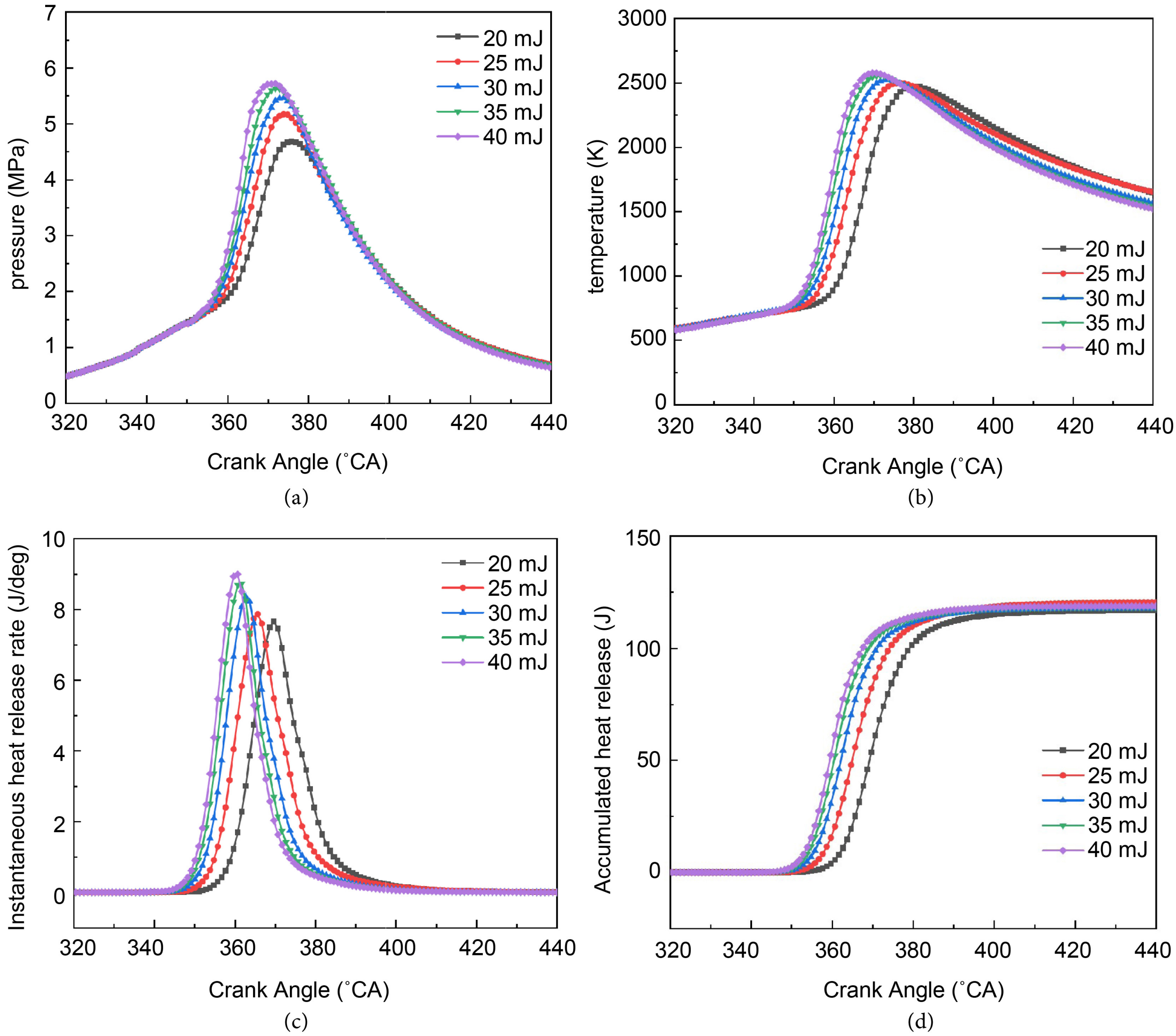


Figure 8. Comparison of combustion parameters in cylinder with different ignition energies. (a) Pressure comparison chart; (b) Temperature comparison chart; (c) Heat release rate comparison chart; (d) Heat release comparison chart.

and temperature inside the cylinder will increase in advance, and the maximum peak value of the average pressure and temperature will also increase. The peak value of the average pressure reached its maximum of 5.72 Mpa at an ignition energy of 40 mj, and appeared at 10 ˚CA after the top dead center. This is because the ignition energy is increased, the size of the spark core is increased, and the development rate of flame combustion is improved. As the ignition energy increases, the rate of change of each parameter decreases.

To investigate the detonation tendency of the engine at different ignition energies, Ki will be used to measure the detonation tendency of the engine. As shown in **Figure 9**, the detonation indices of the five simulation conditions are all higher than 50, indicating that the engine has produced detonation, and as the ignition energy increases, the detonation index gradually increases. This is

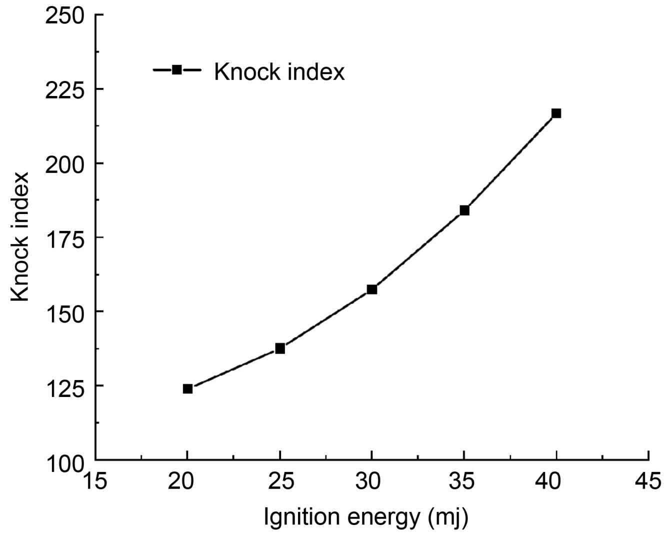


Figure 9. Comparison of combustion parameters in cylinder with different ignition energies.

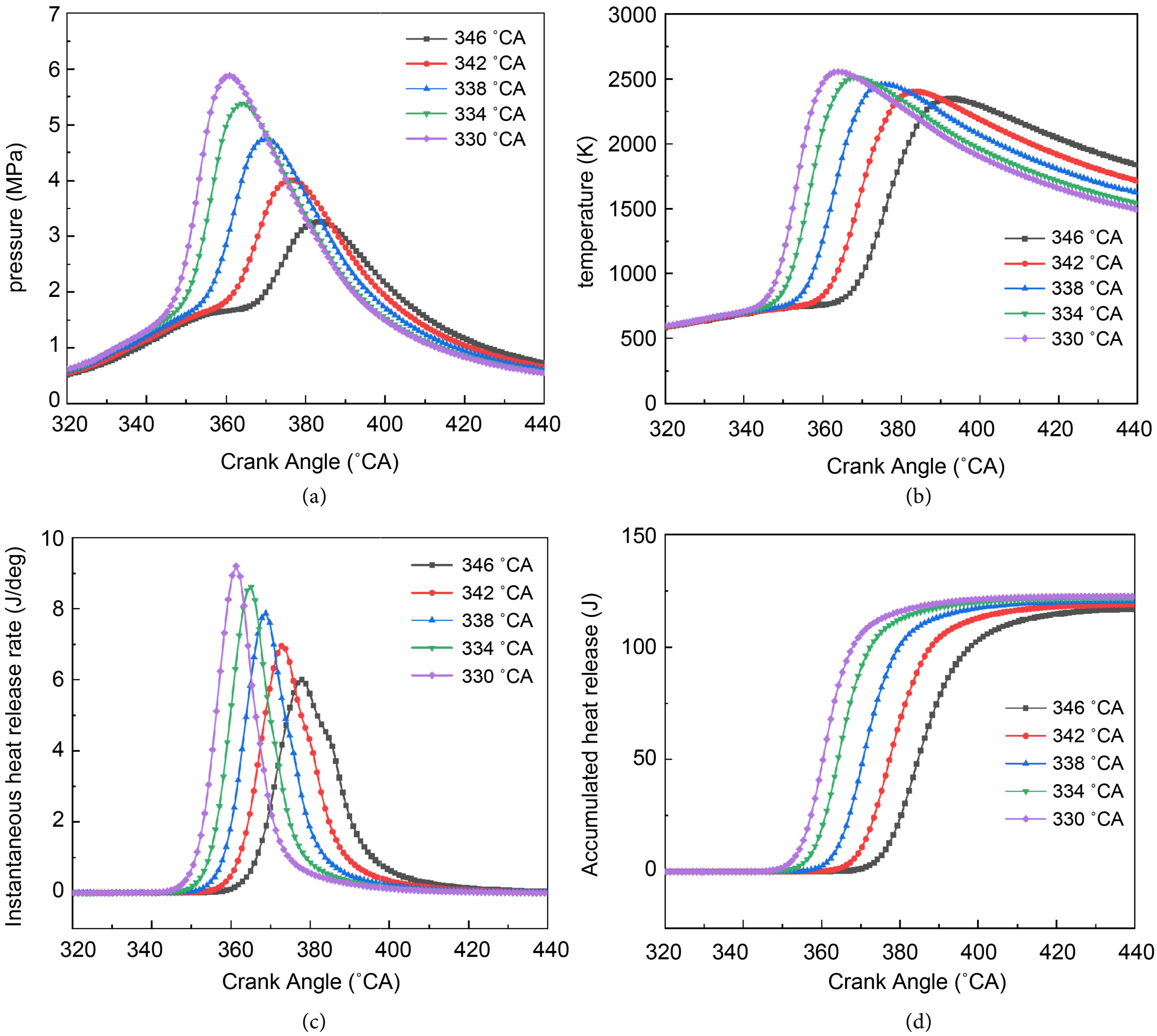
because the higher the ignition energy, the larger the ignition core produced by the spark plug after ignition, and the higher the temperature of the cylinder mixture, resulting in an increased tendency for engine detonation during combustion.

This is because the larger the ignition energy, the larger the ignition core, the higher the temperature of the mixture in the cylinder, which leads to the increase of the detonation tendency of the engine during the combustion process, and the ignition energy decreases after 35 mJ, indicating that with the increase of ignition energy, its promoting effect on detonation is gradually weakened. This is due to the increase of ignition energy, the initial fire nucleus generated by ignition becomes larger, the temperature near the spark plug increases, the flame propagation speed accelerates, and the mixed gas combustion consumption rate accelerates, which reduces the area of detonation distribution area and shortens the duration of detonation combustion reaction.

3.2. The Influence of Ignition Timing on Combustion Characteristics

At a speed of 5500 r/min and a throttle opening of 50%, Ignition energy 30 mJ, the ignition timing of 346 ˚CA, 342 ˚CA, 338 ˚CA, 334 ˚CA, and 330 ˚CA were calculated to study the influence of ignition advance angle on the combustion process of a two-stroke aviation piston engine.

Figures 10(a)-(d) respectively describe the variation of average pressure, average temperature, combustion heat release rate, and cumulative heat release in cylinders with different ignition energies as a function of crankshaft angle. As shown in the figure, as the ignition time advances, the peak values of average pressure and average temperature in the cylinder increase, and the time for the maximum values to appear correspondingly advances. The concentrated heat



(a) (b) (c) (d)

Figure 10. Comparison of combustion parameters in cylinder with different ignition times. (a) Pressure comparison chart; (b) Temperature comparison chart; (c) Heat release rate comparison chart; (d) Heat release comparison chart.

release during combustion gradually transitions from the top dead center to the top dead center, and the combustion duration becomes shorter. The average peak pressure reaches its maximum value of 5.88 Mpa at the ignition time of 330 ˚CA, which occurs at the top dead center. More thermal power conversion occurs during the compression process, which may lead to an increase in the reaction force of the piston generated by combustion in the cylinder, and instead consume a portion of energy. At the ignition time of 346 ˚CA, the minimum average pressure is 3.26 Mpa, which occurs at 21 ˚CA after the top dead center. If the ignition time is too late, the combustion will be pushed back, and the pressure peak will deviate from the top dead center, which is prone to post ignition. A short combustion process is not conducive to complete fuel combustion, and it also leads to the lowest cumulative heat release during combustion at 346 ˚CA,

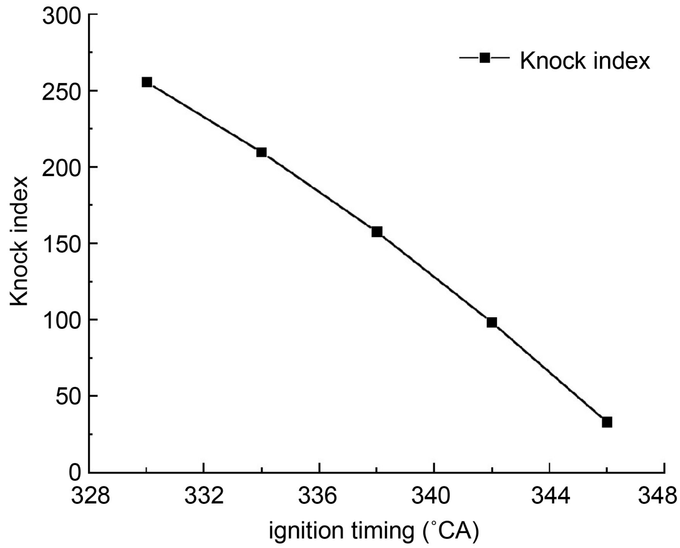


Figure 11. Comparison of detonation index values in cylinders with different ignition times.

resulting in a decrease in engine effective power.

As shown in **Figure 11** the detonation index of the 346 ˚CA simulation working condition is lower than 50, indicating that the engine has not experienced significant detonation. The detonation index of other working conditions is higher than 50, indicating that the engine has a clear tendency to detonation. Moreover, as the ignition time advances, the detonation index gradually increases. This is because the ignition time is too early, and the average pressure and temperature in the cylinder rise quickly. The compression strength of engine has a clear tendency to detonation. Moreover, as the ignition time advances, the detonation index gradually increases. This is because the ignition time is too early, and the average pressure and temperature in the cylinder rise quickly. The average pressure and temperature in the cylinder rise rapidly, the intensity of the end mixture being squeezed becomes greater, the temperature of the mixture at the end of the cylinder rises, and spontaneous combustion reaction occurs in the unburned mixture therein. This leads to an increased tendency for the engine to deflagrate during combustion.

With the advance of the ignition time, the duration of combustion in the cylinder is shortened, and the average pressure peak is close to the top dead center, indicating that the earlier the ignition time, the faster the average propagation speed of the flame in the cylinder, although shortening the flame propagation time can achieve the purpose of reducing the spontaneous combustion reaction time of the terminal unburned mixture and inhibiting the generation of detonation, but because the average pressure and average temperature in the cylinder rise too fast to promote the spontaneous combustion reaction of the unburned mixture at the end, the detonation tendency of the engine increases with the advance of the ignition time.

4. Conclusions

This article takes a small aviation piston engine as the research object, establishes a simulation model, and studies the influence of different ignition times and ignition energy on combustion characteristics when using aviation kerosene. The following conclusions are drawn:

1) As the ignition energy increases, the peak values of average pressure and temperature in the cylinder increase, the combustion duration shortens, the engine combustion efficiency improves, and the tendency for detonation gradually increases. When the ignition energy increases to a certain extent, the impact of the increase in ignition energy on the combustion process weakens.

2) Compared with ignition energy, the impact of ignition timing on engine combustion is more significant. Within a certain range, as the ignition timing advances, the peak values of average pressure and average temperature in the cylinder increase, the center of gravity of combustion gradually approaches the top dead center, and the combustion thermal efficiency improves. However, the tendency for detonation increases more significantly.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Huang, Y.L., Yang, G.W. and Li, Z. (2023) Layered Scavenging Optimization of Two-Stroke Piston Engines in Aviation. *Aviation Engine*, **49**, 47-52. https://doi.org/10.13477/j.cnki.aeroengine.2023.01.006

[2] Huang, K.X., Huang, J.C., Zhang, Y.F., *et al.* (2023) Current Status and Trends of Drone Development in China. *Xiamen Science and Technology*, 59-62.

[3] Wu, H., Zhang, F., Zhang, Z., *et al.* (2020) Experimental Investigation on the Spray Characteristics of a Self-Pressurized Hollow Cone Injector. *Fuel*, **272**, Article ID: 117710. https://doi.org/10.1016/j.fuel.2020.117710

[4] Guo, L.S., Wang, H. and Huang, K.F. (2018) Application of Aviation Heavy Oil in Aviation Piston Engines. *Small Internal Combustion Engine and Vehicle Technology*, **47**, 84-89+93.

[5] Lin, Z.L., Wu, B. and Liu, Q.Q. (2009) Analysis of the Development of Internal Combustion Engine Fuel in China in the Century. *Internal Combustion Engine*, 1-5.

[6] Mosburger, M., Fuschetto, J., Assanis, D., *et al.* (2009) Impact of High Sulfur Military JP-8 Fuel on Heavy Duty Diesel Engine EGR Cooler Condensate. *SAE International Journal of Commercial Vehicles*, **1**, 100-107. https://doi.org/10.4271/2008-01-1081

[7] Yu, G., Li, J.G., Chang, X.Y., *et al.* (2001) Investigation of Kerosene Combustion Characteristics with Pilot Hydrogen in Model Supersonic Combustors. *Journal of Propulsion and Power*, **17**, 1263-1272.

[8] Altin, I. and Bilgin, A. (2009) A Parametric Study on the Performance Parameters of a Twin-Spark SI Engine. *Energy Conversion and Management*, **50**, 1902-1907.

[9] Chen, M.F., Huang, Y.S., Zhang, L., Hou, J.J. and Li, Q. (2011) Comparative Study

on Ignition Performance of Single and Double Spark Plugs in Engines. *Small Internal Combustion Engines and Motorcycles*, **40**, 23-26.

[10] Bei, T.X., Wei, M.X., Liu, R. and Sheng, J. (2017) The Effect of Asynchronous Ignition Phase on Detonation Combustion in Two-Stroke Engines. *Journal of Aerodynamics*, **32**, 322-329. https://doi.org/10.13224/j.cnki.jasp.2017.02.009

[11] Bei, T.X., Wei, M.X., Liu, R., Li, B.L. and Niu, Y.H. (2016) Numerical Simulation of the Effect of Ignition Parameters on the Combustion of Kerosene Piston Engines. *Aircraft Engine*, **42**, 55-59. https://doi.org/10.13477/j.cnki.aeroengine.2016.04.011

[12] Liu, G.M., Sheng, J., Bei, T.X., *et al*. (2020) Effects of Ignition Advance Angle on Combustion and Emissions of Aviation Kerosene Direct Injection Engines. *Energy and Energy Conservation*, 2-7+31. https://doi.org/10.16643/j.cnki.14-1360/td.2020.07.002

[13] Li, X. (2007) Simulation Study on the Combustion Process of CA4102 Natural Gas Engine. Ph.D. Thesis, Jilin University, Changchun.

[14] Liu, Y.R., Chen, W., Zhang, C., Chen, Y.H. and Yan, Z.W. (2021) Research on the Influence of Ignition System on Combustion of a Certain Type of Engine. *Mechanical Manufacturing and Automation*, **50**, 154-158. https://doi.org/10.19344/j.cnki.issn1671-5276.2021.02.041

[15] Chang, C. (2023) Research on Detonation Combustion Characteristics and Suppression Strategy of Ignition Two-Stroke Kerosene Engine. Ph.D. Thesis, Nanjing University of Aeronautics and Astronautics, Nanjing. https://doi.org/10.27239/d.cnki.gnhhu.2020.002453

[16] Zhang, N. (2023) Study on Annular Scavenging Optimization and Combustion Characteristics of Two-Stroke Aero Engin. Master's Thesis, Chongqing Jiaotong University, Chongqing.

[17] Wang, L., Zhao, Z.F., Yu, C.C., *et al*. (2019) Optimization of Exhaust Port Height for Two-Stroke Gasoline Engines with Aviation Pistons. *Journal of Aerodynamics*, **34**, 442-450. https://doi.org/10.13224/j.cnki.jasp.2019.02.020