# Effect of Ejector Channel Arrangement on Performance of Rotating Detonation Ejector

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## 1 Introduction

The rocket-based combined cycle (RBCC) engine has a multi-mode working mode and can work in the whole airspace and full speed range. It is one of the research hotspots and frontier technologies of the new generation of wide-area aircraft [1]. In the low-speed flight stage, the RBCC engine is in the ejection mode, mainly accelerating the aircraft from the static state to the inlet start-up by virtue of the high thrust-weight ratio of the ejector rocket [2]. In the working stage of the ejector mode, the fuel consumption is large and the overall work efficiency is low [3].

Compared with traditional engines, rotating detonation engines have the advantages of high thermal cycle efficiency and low fuel consumption. Compared with the conventional rocket, the rotating detonation ejection enhanced rocket has higher specific thrust, specific impulse and lower initial payload mass ratio [4]. The application of rotating detonation engine to RBCC engine is expected to improve the performance of ejection mode. In the ejector driven by steady-state flow, the flow governing equation describing the ejector performance can be established by simple one-dimensional theoretical analysis method with the help of some basic assumptions and aerodynamic functions. Then the main geometric parameters of the ejector can be obtained by optimizing the design theory. The initial eddy current of the ejector driven by detonation [5,6] has no corresponding relationship with the ejector driven by steady-state flow. Some design methods applicable to it are not applicable to the ejector driven by detonation. The existing relevant reports mainly focus on pulse detonation ejector. In order to provide a basis for the design and selection of pulse detonation ejector, researchers have carried out a large number of experimental studies on the filling rate of detonation chamber [7,8], the geometric characteristics of ejector [9-11], and the location of detonation tube [12-14].

The pulse detonation combustion chamber is mostly a circular tube structure, while the rotating detonation combustion chamber is mostly a coaxial annular. The arrangement of the ejection channel in the rotating detonation ejector will be different from the pulse detonation ejector. In this paper, the ejection channels are arranged on the inside and outside of the rotating detonation coaxial circular combustor respectively, and the influence of the ejection channel layout scheme on the ejection performance is studied, and the influence of the ejector channel arrangement on the ejector performance was studied.

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## 2 Numerical methodology

The coaxial annular combustion chamber is selected as the combustion chamber for rotating detonation injection. The ejector channel is added to the outer and inner sides of the combustion chamber respectively, as shown in Figure 1 (a) and Figure 1 (b), which is referred to as the outer ejector and the inner ejector.

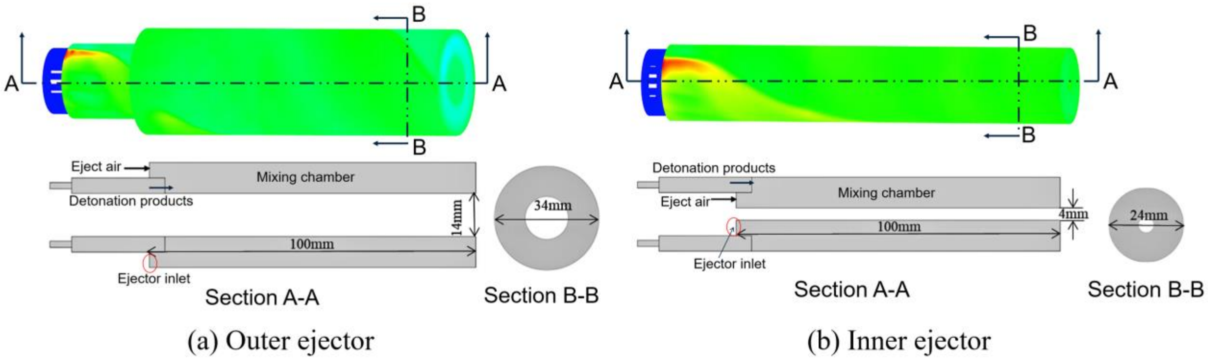



Figure 1: Calculation model of three-dimensional rotating detonation ejector. (The combustion product of rotating detonation is primary flow, and the external air is secondary flow.)

The numerical simulation is based on the finite volume method, while ignoring the condensation phase transition of water vapor, and three-dimensional unsteady Reynolds-averaged Navier-Stokes equations are solved. The turbulence model is the standard k-ε model. The space term is discretized by the second-order TVD scheme, and the time term is discretized by the second-order implicit scheme. The reaction model is a finite rate model of hydrogen-air single step reaction. The inlet condition is supersonic inlet, and the outlet condition is zero gradient extrapolation. The ejector channel inlet condition is pressure inlet, with total pressure of 1 atm and total temperature of 300 K; the rotating detonation combustor inlet condition is pressure inlet, and total pressure is 1Mpa, the total temperature is 300K, and the equivalence ratio of H2/Air mixture is 1. The mixing chamber outlet condition is pressure outlet, and the back pressure is 1 atm. In order to further study the performance of the inner ejector and the outer ejector, different back pressure was set for calculation, and the back pressure was 0.5 atm, 1 atm, 2 atm, and 3 atm respectively.

## 3 Results

During calculation, the ejector inlet was first closed and set as a wall to form a blind cavity. After the detonation combustion product entered the mixing chamber and a relatively stable flow field was established, the ejector inlet was opened and the external air was sucked into the mixing chamber. When the ejector inlet was closed to a blind cavity, the detonation combustion product entered the mixing chamber to establish a relatively stable flow field. The average pressure on the blind cavity wall of the inner ejector and the external of the rotating detonation was calculated respectively, as shown in Table 1. Figure 2 shows the pressure contours of the combustion chamber outlet and the blind cavity wall.

It can be seen that the local high pressure area of the blind cavity in the two ejectors is mainly concentrated at the outer circle wall. The outer circle wall has a certain convergence compression effect, which is not conducive to the diffusion and expansion of the airflow, resulting in higher airflow pressure here. The average pressure on the blind cavity wall of the external is 44.92 kPa, and that of the inner ejector is 98.37 kPa. It can be seen that the external has stronger vacuum ability. Combined with Figure 2, it is clear that compared with the inner ejector, the pressure fluctuation of the blind cavity wall of the outer ejector is relatively small, and the local high pressure area is relatively dispersed and less than the pressure of the external air (1 atm). The pressure of the local high pressure zone in the blind cavity wall of the inner ejector is higher than that of the external air. If the blind cavity is opened to eject the external air, a large number of backflow phenomena will inevitably occur, and the ejection effect is poor. However, the average pressure of the blind cavity wall is lower than the pressure of the external air, and it has a certain ejection ability.

Table 1: The average pressure of the blind cavity wall (back pressure is 1atm).

| Location of ejecting channel arrangement | The average pressure of the blind cavity wall /(kPa) |
|---|---|
| inner | 44.92 |
| outer | 98.37 |

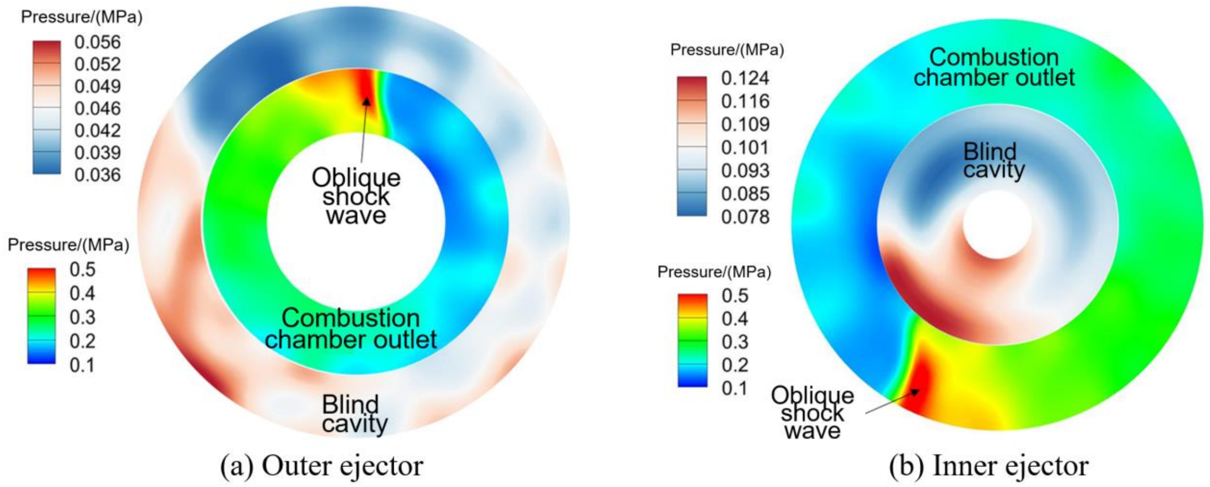
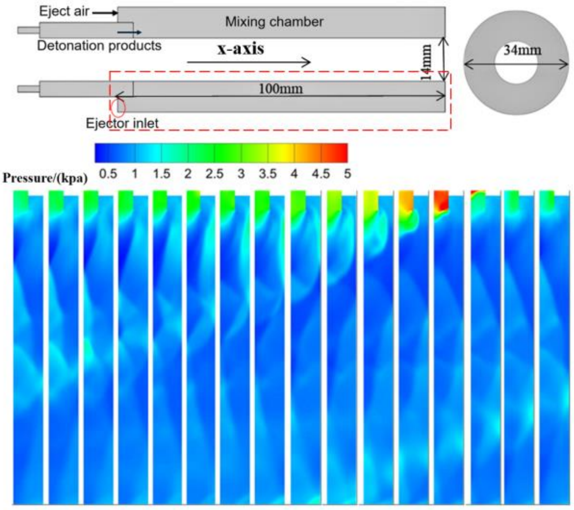


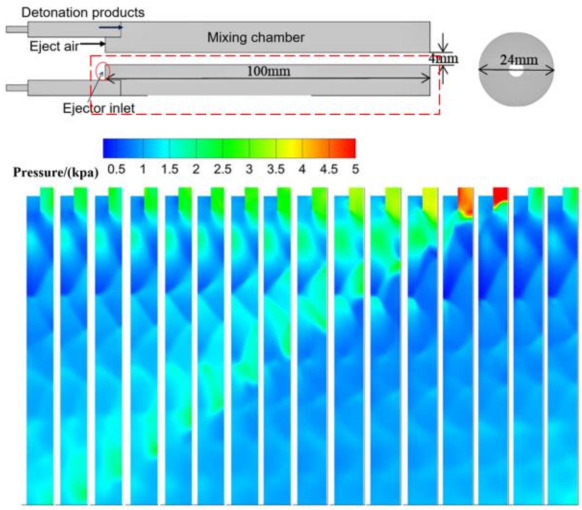

Figure 2: The contrast pressure cloud diagram of the combustion chamber outlet and the blind cavity wall.

Then, the ejection channel of the inner ejector and the outer ejector was opened, and the external air entered the mixing chamber under the action of the detonation product. Figure 3 shows the pressure cloud diagram of the internal sections of outer ejector and inner ejector at the same time. It can be seen that the oblique shock wave expands in the axial and radial positions of the mixing chamber after being discharged from the detonation combustion chamber. When the shock wave hits the wall of the mixing chamber, the static pressure rapidly increases and forms a reflected shock wave. As shown in Figure 3 (b) and (d), in the inner ejector, the oblique shock wave expands from the outer circle wall to the inner circle wall, the flow area becomes smaller and the outer circular wall has a convergence effect on the airflow, which hinders the expansion of the oblique shock wave. As shown in Figure 3 (a) and (c), in the outer ejector, the oblique shock wave expands from the inner circle wall to the outer circle wall, the flow area becomes larger and the inner circular wall has a diffusion effect on the airflow, which is beneficial to the expansion of the oblique shock wave.

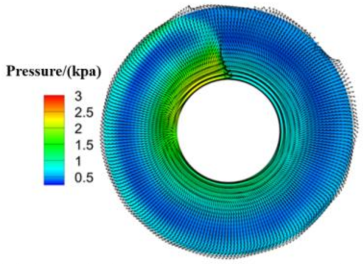
The ejector coefficient is the ratio of the mass flow rate of the secondary flow to that of the primary flow, reflecting the ability of the ejector to pump gas, and is one of the main evaluation parameters of ejector performance. When a relatively stable flow field was established, the ejection coefficients were calculated, and the calculation results are shown in Table 2. The ejection coefficient of the outer ejector is 0.288, and that of the inner ejector is 0.00623.Compared with the inner ejector, the flow channel of the outer ejector is beneficial to the expansion process of the detonation product, and the air inlet area of the outer ejector is larger, so the outer ejector has a good ability to suck gas.



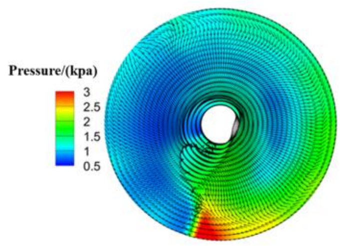

(a) The different axial sections (outer ejector).




(b) The different axial sections (inner ejector).




(c) The radial section (x=35 mm, outer ejector).




(d) The radial section (x=35 mm, inner ejector).

Figure 3: The pressure cloud diagram of the internal sections of outer ejector and inner ejector.

Table 2: Ejector coefficient of the inner ejector and the outer ejector.

| Location of ejecting channel arrangement | Ejector coefficient |
|---|---|
| inner | 0.00623 |
| outer | 0.288 |

It can be seen from the above analysis that the local high pressure area in the blind cavity of the inner ejector is larger than the external air pressure. After opening the blind cavity, the detonation product will flow out from here, but the average pressure in the blind cavity wall is slightly smaller than the external air pressure, and a small amount of air is still sucked into the mixing chamber.

The ejector field of the inner ejector and the outer ejector was calculated under different back pressure. Table 3 shows the average pressure of the inner ejector and the outer ejector on the blind cavity wall under different back pressure. As shown in Table 3, in the inner ejector, when the back pressure is 0.5 atm, 1 atm and 2 atm, the average pressure on the blind cavity wall changes slightly. When the back pressure rises to 3 atm, the pressure of the blind cavity wall suddenly rises to 194.21kPa, which is higher than the pressure of the external air, and the ejection capability is not available. In the outer ejector, when the back pressure is 0.5 atm and 1 atm, the average pressure on the blind cavity wall changes slightly; when the back pressure rises to 2 atm, the average pressure on the blind cavity wall rises to 85.79kPa; when the back pressure rises to 3 atm, the average pressure on the blind cavity wall is higher than the pressure of the external air, and the ejection capability is not available.

Table 3: The average pressure of the blind cavity wall under different back pressure.

| Back pressure/atm | The average pressure of the blind cavity wall of the inner ejector /(kPa) | The average pressure of the blind cavity wall of the outer ejector /(kPa) |
|---|---|---|
| 0.5 | 96.85 | 44.92 |
| 1 | 98.37 | 45.04 |
| 2 | 98.44 | 85.79 |
| 3 | 194.21 | 219.96 |

The pressurization ratio is the ratio of the total pressure of the fluid at the mixing chamber outlet to that of the secondary flow, which reflects the work capacity of the fluid after mixing and is one of the main evaluation parameters of the ejection performance. Table 4 shows the ejection coefficients and the pressurization ratios of the inner ejector and the outer ejector under different back pressure. For a steady state ejector with a fixed geometry, the pressurization ratio and ejector coefficient change in the opposite trend, while for a rotating detonation ejector, the change trend is the same. Since the ejection coefficient is more affected by temperature, the pressurization ratio is more affected than total pressure.

Table 4: Ejection coefficient under different back pressure.

| Location of ejecting channel arrangement | Back pressure/atm | Ejector coefficient | Pressurization ratio |
|---|---|---|---|
| inner | 0.5 | 0.0094 | 3.72 |
| inner | 1 | 0.0072 | 3.717 |
| inner | 2 | 0.0069 | 3.6 |
| outer | 0.5 | 0.2887 | 2.843 |
| outer | 1 | 0.2883 | 2.798 |
| outer | 2 | 0.141 | 2.59 |

## 4 Conclusion

In this paper, the ejection channels are arranged on the inside and outside of the rotating detonation coaxial annular combustor respectively. Numerical study on the flow process of inner and outer jets of rotating detonation was carried out. The results show that under the current geometric conditions, the flow channel of the outer injector is conducive to the expansion process of detonation products, and the air inlet area of the outer injector is larger. Therefore, when the injection channel is arranged outside the detonation combustion chamber, the ejector effect is better. Since the temperature and total pressure of RDE product increase with the increase of the detonation intensity, the variation trend of the ejection coefficient and the pressure ratio of RDE ejector is the same.

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