Numerical Investigation of components length of china-type valveless pulsejet

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Abstract—**Due to its simplicity in structure and reliability in performance, the valveless pulsejet may be the most ideal low cost propulsion system for small-sized aerospace vehicle. A series of numerical simulations are performed to understand the variation of flow field and to research the performance in china type valveless pulsejet. CFD software(CFX11.0) is used to numerically predict components length's influence on pulsejet's performance. Evidence is provided that the frequency of china valveless pulsejet increases with the decrease of the length of the tail and the combustor. Pulsejet can't work properly if tail length below the limitation. There is an optimized length for tail and combustor, which is the best for the performance and operation stability.**

Keywords-pulse jet, valveless, numerical simulation, turbulence combustion, multi-cycle

I. INTRODUCTION

Lots of significant works on the pulsejets were conducted before the mid 1950's and esearches were terminated for its relative low efficiency. However, within the past two decades, pulsejet has gained ebullient research attention because of its great heat capacity intensity, air-breathing, simplicity, less moving parts, high thrust to weight ratio and extremely low cost. There's widely application prospect [1-4] in new concepts propulsion system, such as unmanned aerial vehicle, scout missile, target aircraft through, by utilizing small scale valve or valveless pulsejets as an efficient, affordable and durable propel engine. Pulsejets operate on a thermodynamic cycle, which lays some state in between isochoric cycle and isobaric cycle. As to valveless pulsejet, it strictly relies on the dynamics of the pressure waves in the intake and exhaust. As soon as a working cycle of pulsejet is completed, the inertia of the exhaust hot gasses leads to an over expansion, which creates a negative pressure in the combustion chamber in turn. And then, fresh air and fuel are inhaled into the combustion chamber and are autoignited by remaining hot products by last working cycle. As to china style pulsejet, inlet of the pulsejet acts as an aero-valve, which helps to ignite fresh air-fuel mixture. Then the cycle repeats itself.

Experiment's ability to understand transient flow field in the pulsejet is restricted by the adverse work circumstance and the absence of accurate effective measurement method for intense oscillation and drastic dynamic change existing in working process of pulsejet, which leads that design and optimization of the pulsejet mainly depends on expensive and difficult experiment measurement. With the development of computer technology and Computational Fluid Dynamics (CFD) [5-7], numerical simulation is utilized to recognize complicated two-phase reaction turbulent flow process and to direct pulsejet's optimum design [8], which can reduce the cost and the cycle of experiment research. Estimation model [9] has been established and been used to predict performance of valveless pulsejet, which is based on thermodynamic and acoustic theory and lacks of the information of the three-dimension turbulent reaction flow field and the consideration of influence factors in pulsejet. Furthermore, CFD can be used to observe combustor's detailed internal parameters, which is very hard or extremely expensive if just gained by experiment study and able to provide excellent help in aero engine optimization. In this paper, an investigation is conducted in order to understand how china-type pulsejet performance depends on the length of tail and the combustor, by utilizing numerical simulation of multi-cycle working process in such pulsejets. So, computer simulations are performed to study multi-cycle working process in china-type valveless pulsejet and to predict the performance of researched objects by using of general CFD package (CFX^{TM} 11.0).

II. RESEARCH OBJECTS

A typical china-type valveless pulsejet, as shown in Fig.1, is numerically researched to understand the change process of reaction flow field to consider the influence of the length of the combustor and tail. During all numerical simulations, propane is used as the fuel and fed into the pulsejets through fuel tube at a constant flow rate of 0.4g/s. Total length of the pulsejet is 830mm and detailed structure of simulation objects can be found in Fig.1. Separated mesh of pulsejet is shown in Fig.2. All simulated regions includes interior of the pulsejet and the extended zones for considering the influence of flow field around the researched object, as shown in Fig.3. All meshes are generated in 360 deg region by use of Gambit ^{TM} and total number of meshes is 88082. In order to observe the exchange processes of mass, momentum, energy and components between the pulsejet and surrounded environment, farfields are set near the inlet and the outlet, respectively. Diameter and length of the farfields are 5 times and 10 times of the representative diameter, respectively. Because boundaries are set enough far away from the pulsejet, far flowfield's effects on the pulsejet can be negligible. So, boundary condition of farfield can be set to temperature T_0 equal to 300K and pressure P_0 equal to 1atm. Three monitoring points are set as shown in Fig.4.

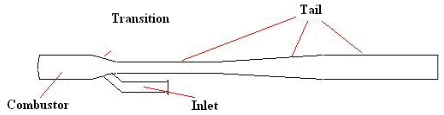

Figure 1. structure diagram of china-type pulsejet

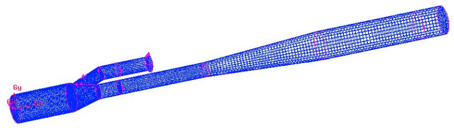

Figure 2. mesh of researched pulsejet

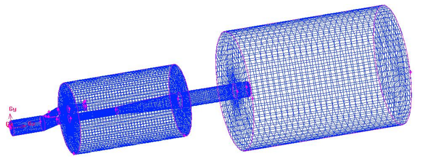

Figure 3. mesh of whole flow field

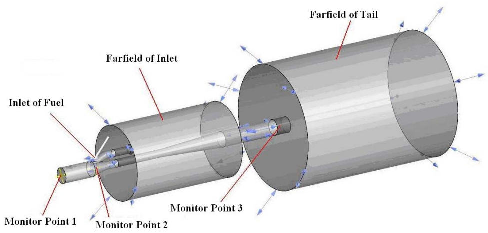

Figure 4. boundaries and monitor points

III. NUMERICAL MODELS AND METHODS

The computations are performed on IBM Core2 Duo 2.26GHz processor. Typical computational time for whole simulation (0.06s) is about 100h.In numerical simulations, the second order transient scheme and high-resolution advection scheme and high-resolution advection scheme are used to discrete general governing equation. The timestep is set to 10^{-5}s and the convergence criterion is set to 10^{-4} in residual mean square value.

A. Wall temperature

There is a significant heat flux between the pulsejet wall and fluid inside and outside the pulsejet. For frequency of the pulsejet is very high and thermal inertia of the wall is enough, temperature of walls [9] can be assumed to be steady and be simplified as shown as segmented Eq.1. Temperature of combustion chamber wall is equal to 1000K and temperature of the inlet point and the outlet point is equal to 400. It linear changes with the distance along axial direction that temperature distribution between combustor and the inlet and t temperature distribution between combustor and the outlet.

$$\begin{cases} T_{\mathrm{InletWall}} = az + b & (\quad z < 0.0 \quad) \\ T_{\mathrm{CombustorWall}} = c & (0 < z < 0.076) \\ T_{\mathrm{TailWall}} = dz + e & (\quad z > 0.076 \quad) \end{cases} \tag{1}$$

B. Numerical models

To consider three-dimensional, unsteady, compressible, viscous flow in the valveless pulsejet with heat transfer, combustion and radiation, RNG *k*- ε turbulent model, P1 [11] radiative model and EDM turbulent combustion model [12] is adopted in this paper. A propane-air five step reaction mechanism [13] provided by CFX is used to simulate the combustion process. The field near the wall is dealt by boundary function.

IV. RESULTS AND DISCUSSIONS

A. Analysis of pulsejet cycle

Through the numerical simulation of china-type valveless pulsejet, working cycle of the pulsejet can be observed clearly through analyzing the variation process of temperature, oxygen mass fraction in the pulsejet. Part results gained from numerical simulation are shown in Fig.5~Fig.12. Fig.5 and Fig.6 shows variation process of the temperature and the oxygen mass fraction in one cycle which can be described by the following 5 steps:

1) The completeness of combustion of the reactant mixture is the highest and the combustor is filled with hot combustion gas. Hot products continue to be expelled from the exhaust duct but the velocity continuously decreases, which causes low pressure in the combustor for the Kadenacy effect. It should be pointed out that the propane is burnt out near the end of the intake. When the pressure of the hot gases becomes equal to the pressure of the cold air, the velocity goes to zero at the interface of these two gases.

2) For the lower pressure in the combustor caused by Step.1, the fresh air flows into the turbine through the inlet and the tail. Only the air coming from the inlet goes into the combustor as the oxidant, which will react with the propane coming from the fuel inlet. The backflow velocity in the inlet is higher than that in the tail and the pressure in the combustor increases a bit for the effect of the backflow's compression.

3) The hot combustion surviving in the combustor and coming from the tail direction ignites the fresh air-propane mixture. In the combustor, the temperature starts to increase and the pressure continues to become high. In the inlet, the degree of the backflow reaches the maximum condition.

4) The fresh air-propane continues to combust. In the combustor, the pressure and temperature continuously increases. The high temperature combustion gas moves to the inlet and the tail and the expansion wave is generated.

5) The pressure and temperature continuously increases near the inlet and the exhaust velocity reaches the highest. In the tail, the degree of the backflow reaches the maximum distance.

From the computational results, it can be observed that chemical reaction consumes most of the oxygen in the pulsejet except the inlet tune and the bottom of the combustor. The oxygen needed for the combustor only comes from the inlet. The inlet determines the amount of air entering the combustion chamber. The fresh air coming through the tail flow back to the tail in some distance and is pushed out the turbine by generated hot gas coming from the new cycle.

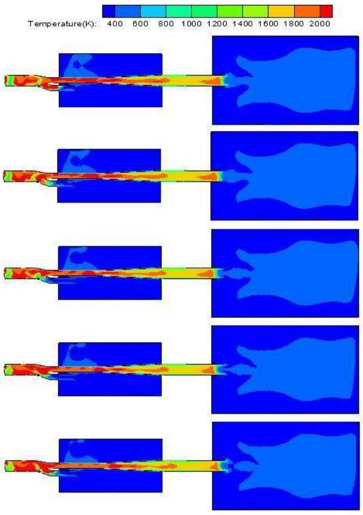

Figure 5. Variation of temperature in one cycle

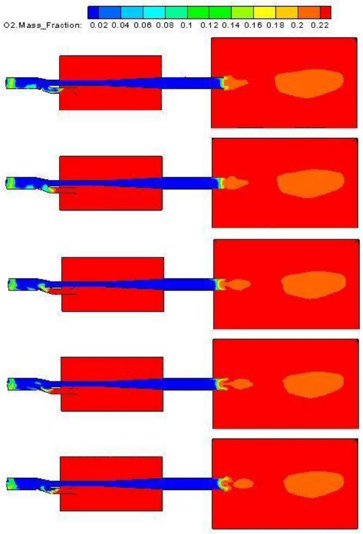

Figure 6. Variation of O2 mass fraction in one cycle

B. Working process of multi-cycle

Fig.7~Fig.10 show the variation processes of absolute pressure, propane mass fraction and temperature at different monitor point between 0.04s and 0.052s. The pulsejet cycle contains information about the properties relative to combustion, flow, and heat transfer. From above three figures, there are three fluctuations and one cycle lasts about 0.004s. And then, the frequency of this china-type valveless pulsejet is about 250Hz. As shown in Fig.7, variation of the pressure isn't smooth in one cycle at Monitor.1. As shown in Fig.8, it can be found that mass fraction is very high at Monitor.2, which verifies with the time for intermittent combustion phenomenon in the combustor.

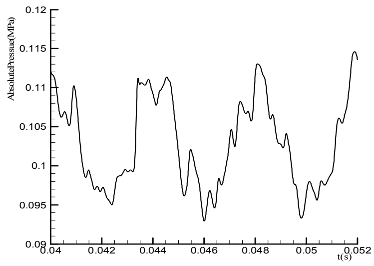

Figure 7. Variation of pressure at Monitor.1

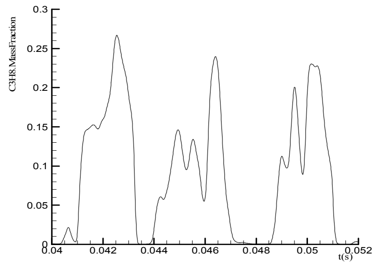

Figure 8. Variation of propane at Monitor.2

As shown in Fig.9, it can be observed that there is very little of the propane at Monitor.3 because combustion efficiency in the pulsejet is very high. Fig.10 shows the variation process of the temperature at the same position, which is in the inner side of the outlet plane. In this point, the lowest temperature is higher than environment temperature, which verifies that backflow of the fresh air in the tail isn't enough strong to cooling the hot temperature exhaust.

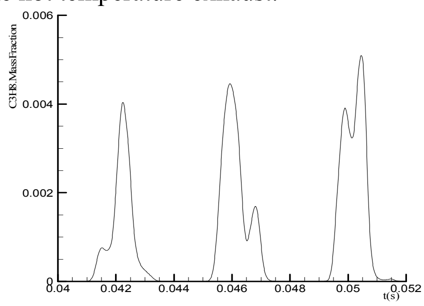

Figure 9. Variation of propane at Monitor.3

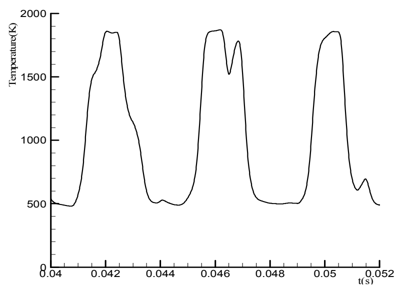

Figure 10. Variation of temperature at Monitor.3

Fig.11 shows pressure variation process at Monitor.1 when changing the length of the tail. As shown in Fig.12, computational results show that the frequency is the lowest when the length of the tail subtracting 50mm from the base model (Case 2) and the frequency increases with the increase of tail's length relative to that in Case2, which is relative difference with experience option about the straight flow pulsejet. The max absolute pressure is the highest in Case2. From about phenomena, it can be observed that there is a optimal length of the right circular cylinder of the tail for decreasing the frequency of the china-type valveless pulsejet. Such phenomena should be examined by further research of simulations and experiment.

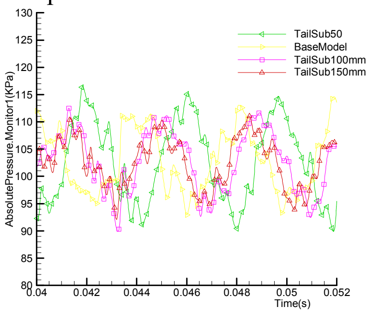

Figure 11. variation of pressure at Monitor1

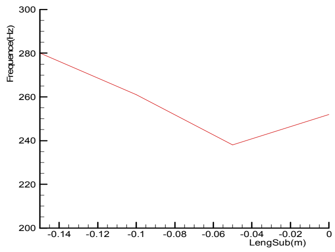

Figure 12. Frequency variation with the change of length

As shown in Fig.13, computational results show that the frequency of the base model is the lowest and the frequency increases with the decrease of combustor's length. When the cut part is shorter than 30mm, the increase of the frequency is very slow. And it increases rapidly when the cut part is longer than 30mm. The combustion of air-fuel mixture mainly exists in the combustor near the inlet and the bottom of the combustor only reacts as one of high temperature igniters, which may be the reason of such phenomena.

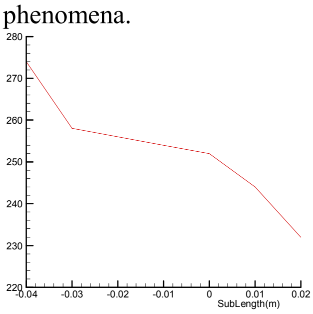

Figure 13. Frequency with the change of combustor

V. CONCLUSION

From the computational investigation, the following conclusions are obtained.

1) In one cycle of the pulse combustion, the key parameters change alternatively in the inlet and the tail, which operates in the match of the whole cycle.

2) Suction-exhaust process of the pulsejet proceeds alternatively, which brings the fresh propane and the air into the combustor. The propane-air mixture is ignited by existing combustion production of the last multi-cycles and the combustion mainly happens near the inlet in the combustor, which maintains the continuous work of the china-type valveless pulsejet.

3) Through observing the results of the numerical research, the frequency of the researched valveless pulsejet is about 250Hz.

4) The length of right circular cylinder of the tail effects the frequency of the china-type valveless pulsejet and there is a most optimal length for the decrease of the frequency.

5) The frequency of the pulsejet varieties nonlinearly with the decrease of the length of the combustor. And the frequency will increase quickly when the decrease length is more than 30mm.

ACKNOWLEDGMENT

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