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Numerical Analysis of Cross Section Time Variation Effects of the Supersonic Exhaust Diffuser

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ABSTRACT: This paper is presented to investigate the deposition effect on a second throat exhaust diffuser performance. In the numerical simulation, the blockage of the diffuser due to the deposition of aluminum oxide is considered by a gradual and time-dependent cross-section constriction. In the initial conditions, the supersonic flow has been established in the nozzle and diffuser. Diffuser cross-section area is reduced by using a dynamic mesh method during the solution. The flow is considered compressible, viscous, and 2 dimensional axis-symmetric. The k-ω shear stress transport turbulence model is used to solve the turbulent flow field. Diffuser blockage (n) is equal to the ratio of instantaneous and primary diameters of the second-throat. By changing the value of n from 1 to 0.75, the onset of flow separation is moved to the downstream location in the diffuser. This results in a considerable reduction of total pressure loss and then improves the flow pressure recovery. Decreasing parameter n from 0.75 to 0.64, the flow structure is subjected to severe changes and the separation of the flow occurs near the diffuser inlet or inside the nozzle. In this condition, the diffuser state changes from starting to un-starting mode. Therefore, the vacuum condition vanishes in the test chamber.

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1. Introduction

There are often some aluminum particles in the composite solid propellant, which are utilized in Space engines. These materials are converted to a melt module, which will be exited accompanying with some combusted gases via nozzles. Because of this point that the freezing temperature of aluminum oxide is very high (more than 2072°C), it can be seen that if the temperature of these materials decreases in any kinds of circumstances, it will be probably glued in the nozzle walls with solid shape.

Based on Farber *et al.* [1] research, there are three analyses for a deposition sample by an X-Ray equipment which is coming from the interior part of a nozzle. It has been shown from the analyses that there is some aluminum oxide in the nozzles. Furthermore, there have been reported some deposition of the aluminum oxide particles at the ending sections of nozzles [2-4].

Researchers are mostly utilizing high altitude test facility for motors with long nozzle in the ground tests. As shown in schematic picture (Fig. 1), there is a main core of a high altitude test stand.

There have been some research about high altitude test by Space Transportation Research Institute (STRI) which depicts, there are some thick aluminum oxide layers at the interior sections of the diffuser, especially wherein the flow separation occurs. It is worthy to mention that for protecting diffuser metal body from melting, spraying toward the outer layers is employed to decrease its significant hot temperature. It can be said that the outer layer temperature is less than 700 K [5]. In the following, there is a creation of aluminum oxide deposition layers at the interior section because of cooling the body of the diffuser.

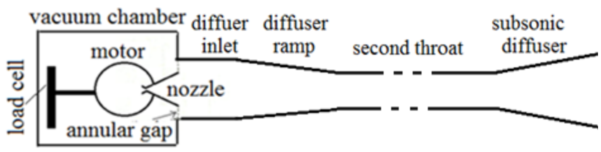

Fig. 1. Schematic diagram of high altitude facility

Unfortunately, there have been reported few researches about hot gas tests in high altitude test facility. Furthermore, there has not yet been seen any researches related to accumulated aluminum oxide deposition in the interior surface of the diffuser in exception with a research which has reported gathering deposition particles at ONREA institute in France which was a mechanical approach [6].

Since the deposition of aluminum oxide causes a change in the cross-section area of exhaust diffuser, investigation of deposition effect on diffuser performance during motor operation can help the researchers to walk on the true way in the decision-making process

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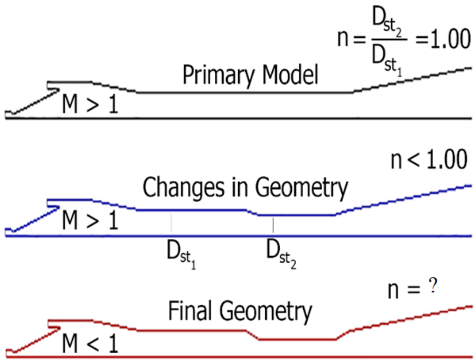

Fig. 2. Schematic diagram of the second throat constriction

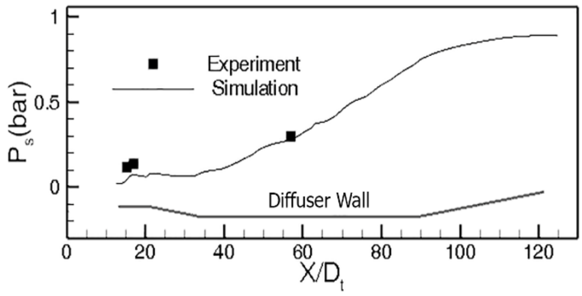

Fig. 3. Comparison of computed and measured pressures along the diffuser

This study is neither relating the procedure of accumulating of aluminum oxide deposition layers at the interior walls of a diffuser nor its quantity estimation. The aim of this research is investigating the causes of its canal obstruction in the high altitude test facility performance.

2. Problem Definition and Numerical Method

Due to the high momentum of the flow at the inlet section of the diffuser, the deposition is not mainly stuck to the wall. But because of the flow separation, a lot of deposition will be accumulated at the ending section of the diffuser. So that, it is assumed that there is some deposition at the semi-ending section of the second throat. The experimental tests also confirmed this process of deposition formation [7]. Fig. 2 shows a schematic of canal constriction.

3. Results and Discussion

In this study, the validation of numerical approach has been investigated by utilizing the test results of an experimental motor test in high altitude test facility at space transportation research institute. The computed results by the numerical method are compared with experimental data (Fig. 3), which is shown a good agreement.

The purpose of this section is investigating the influence of constricted cross section at flow physics. For this reason, constriction parameter, n, has been defined as an amount for specifying the variable diameter of second part of second throat per constant diameter of the first part. In the initial condition, there is no constriction in second throat, thus n must be equal to one.

The flow Mach number contour in distinct constriction parameters has been shown in Fig. 4. When n is equal 1, supersonic flow is being created in the nozzle and in the inlet section of the diffuser. By decreasing of n, the separation area in the first part of second throat will be lower, moreover, the supersonic flow area will be expanded more and the pattern of the flow will be improved in the diffuser. In the next, when n is changed from n=0.7 to n=0.67, it leads to flow disruption inside the diffuser. In this condition, the pressure is increasing in the vacuum chamber. Whereas, nozzle is still in the start mode. In the following, by decreasing n to 0.64, the separation point is moving into the nozzle, and both of nozzle and diffuser will be in unstart modes.

Further investigation shows that the separation point is moved to the downstream by increasing constriction until n=0.8. When n is equal to 0.7, the separation point is moved to the inlet of the diffuser. The reason of this matter is regarding to the supersonic flow that is kept up much more at the length of the diffuser. By increasing the constriction (n=0.64), flow is choked and the diffuser is exited from start mode. Based on the shock function contour in Fig. 5, it can be seen that the number of shock waves with weak strength is increased based

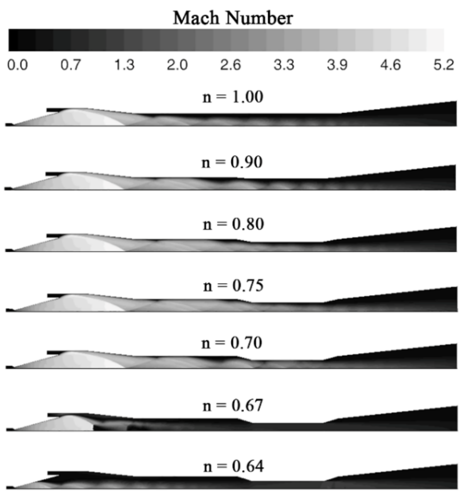

Fig. 4. Mach number contour variations with constriction

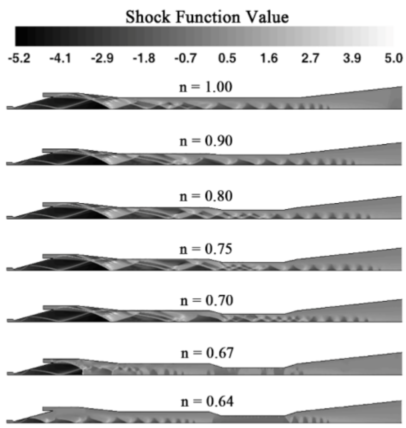

Fig. 5. Shock function contour

on the contour of the shock function (Fig. 5) by constricting the channel from n equal 1 to 0.7. There are some significant changes in structure of shock waves in n=0.64 and n=0.67. By decreasing the cross section (n=0.64), the second part of the second throat is choked and the supersonic flow will not be created at the inlet of the diffuser.

4. Conclusions

In present study, the effect of second throat blockage of supersonic diffuser in high altitude test facility was numerically investigated. Results have shown that, constriction of second throat from 1 to 0.7, not only does not cause disruption in diffuser performance but also, it has further developed the supersonic flow during the diffuser. On the other hand, shown that further reduction of parameter n, is Causing suffocation of flow in this region and, poor performance of diffuser.

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