Studies on Linear Aerospike Nozzle

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1. Nomenclature

A_t: Throat area of cell nozzle
C_{FMcell}: Theoretical thrust coefficient of cell nozzle for momentum force
C_{F,E}: Thrust coefficient of aerospike nozzle
P_{cell}: Plenum pressure of cell combustor
P_{cell, exit}: Pressure at cell nozzle exit
P_W: Pressure on the spike surface
P_a: Ambient pressure
P_B: Pressure at truncated nozzle base surface
P_T: Calculated pressures at the end of the full-spike nozzle
P_E: Calculated pressures at the truncated point
\|B: Ratio of truncated nozzle base area and total throat area
\|c: Expansion area ratio of cell nozzle
\|c_e: Expansion area ratio of spike nozzle
\|c: Tilt angle of cell nozzle to the spike axis
\|CF: Thrust coefficient efficiency
\|: A correction factor for the thrust of a cell nozzle
NPR: Nozzle pressure ratio, P_{cell}/P_a

2. Introduction

For future fully reusable SSTOs, reusable rocket engines characterized by light weight and high performance from low altitude to high altitude are essential. Engines with aerospike nozzles are drawing attention as promising candidates which satisfy these requirements. The National Aerospace Laboratory has studied aerospike nozzles for the past few years.1-5

To clarify the causes of thrust performance loss in a clustered linear aerospike nozzle, a 14 kN thruster of a clustered linear aerospike nozzle composed of six rectangular cell nozzles and a two-dimensional truncated spike nozzle was fired. To acquire detailed information on the loss due to the clustering of cell nozzles, cold flow tests with a subscale model were also conducted.

Performance of Linear Aerospike Nozzles

The theoretical thrust coefficient of two-dimensional linear aerospike nozzles can be calculated by the following equation:5

\[ C_{F,E} = C_{FMcell} \cos \|c_{cell} + \|c_{cell} \cos \|_{cell} + \|P_WdY \]

\[ + \|_B \frac{P_B}{P_{cell}} - \|_E \frac{P_a}{P_{cell}} \]

\[ \frac{P_B}{P_{cell}} = 0.3(P_T + P_E) \]

Figure 1 shows the observed \|CF, as a function of NPR with the theoretical efficiency and CFD result. For the aerospike nozzle, the predicted \|CF was about 0.91 and measured \|CF, were about 0.85 at NPR= 10. The value of the computed \|CF agrees well with the experimental data. Based on a simple modeling, the \|CF loss due to the total pressure loss by the oblique shock was calculated. The results indicate that \|CF decreases as NPR goes down. Needless to say, the oblique shock may be one of the causes for the decline of nozzle efficiency, especially at low NPR conditions.

Combustion Tests with a 14 kN Clustered Linear Aerospike Nozzle Thruster

The experiments and the analysis shown above dealt only with a linear aerospike nozzle composed of two-dimensional cell nozzles. In reality, high cooling requirements, because of the greater surface area to be cooled, rule out this simple configuration. To overcome this difficulty, clustered cell nozzles are used.

Figure 2 shows a photograph of the combustion test with the 14 kN clustered linear aerospike nozzle. Figure 3 shows the measured \|CF as a function of NPR with the predicted \|CF. The conditions tested were at ground-level. The obtained \|CF, were only 0.875, which was remarkably low in comparison with the predicted value, 0.97. The main causes of the loss observed were considered to be the loss from the flow characteristics of linear aerospike nozzles and the loss due to clustering, i.e., loss due to the gaps between cell nozzles.

3-Cell-Clustered Cold Flow Model Tests

To clarify the cause of the loss due to clustering, cold-flow tests were carried out with the 3-cell-clus-
tered nozzle model composed of three cell nozzles which is arrayed with gaps and a flat plate nozzle.

The lower half of Fig. 4 shows a visualized image using the shadowgraph technique, and the upper shows NDP = (P_W - P_a)/P_{cell} distribution on the flat plate nozzle at the optimum NPR of the cell nozzle.

From the result, the main causes of the loss due to the clustering were the pressure force on the gaps and total pressure loss due to oblique shocks which were observed from wakes of the gap. A simple model to estimate thrust performance of clustered linear aerospike nozzles is proposed. The model uses only the design values of nozzles. The model is as follows:

(1) Loss in cell nozzles is only the divergent loss.
(2) The thrust of the gap surface is (P_g - P_a)A_g, where P_g was calculated by the same approach as that of P_B.
(3) The performance loss due to the total pressure loss from re-compression shock, P_{02}/P_{01}, is calculated using ordinary step flow model.

This model was applied to the 14 kN clustered linear aerospike nozzle, \( \eta_{CR} = 0.945 \). The difference from the ideal value, 0.025, is the loss due to the clustering. The observed \( \eta_{CR} \) for the 14 kN aerospike nozzle was only 0.875, and thus the cause of the loss of about 7% is still unknown.

**Reference**


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Fig.2 Combustion test of 14kN clustered linear aerospike nozzle

Fig.3 Observed Thrust coefficient efficiency as a function of NPR

Fig.4 Observed NDP distribution and visualized image using the shadow graph technique