INTERACTION OF SUPERSONIC FLOWS IN AN EJECTOR

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Summary The article deals with experimental, theoretical and numerical study of the interaction of supersonic flows on the trailing edge of a primary flow nozzle of an ejector. The mechanism of mutual deflection of supersonic flows is explained. The influences of back pressure ratio and stagnation pressure ratio of both flows on the interaction are presented. Recommendations for design and for operation of supersonic ejectors are formulated.

INTRODUCTION

The geometry of the trailing edge of the primary flow nozzle of a supersonic ejector is visible on Figure 1a. If the back pressure ratio is sufficiently low, both flows are supersonic and the interaction of supersonic flows on the trailing edge occurs. We studied this interaction by means of experimental, theoretical and numerical methods [1]. We used schlieren and interferometric methods to visualise two-dimensional flow field. We used Fluent 6.0 program for numerical computation and we get theoretical results with help of relations of shock waves theory. We observed that there can be two different solution for given stagnation pressure ratio and that the process of mutual deflection of supersonic flows is more complicated. The aim of this study is to understand the interaction and how it influences the mixing processes in the ejector. It allows us to optimise the design and operation of supersonic ejectors.

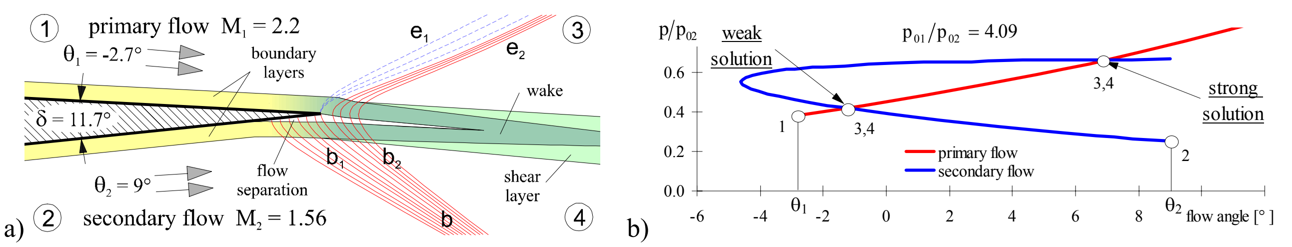

Figure 1: The interaction of supersonic flows on the trailing edge of the primary flow nozzle; a - scheme, b - theoretical solution for the regime of $p_{01}/p_{02} = 4.09$.

RESULTS

The influence of the back pressure ratio p_p/p_{02} was investigated for stagnation pressure ratio $p_{01}/p_{02} = 4.09$. The possibility of two different solutions of the interaction of supersonic flows on the trailing edge of the primary flow nozzle can by explained with help of theoretical results on Figure 1b. The two pressure-deflection shock polars representing both flows in diagram static pressure ratio - flow angle have two common points representing two solutions. The sum of deflection of both flows is given by the angle of the trailing edge δ .When the back pressure ratio is $p_p/p_{02} =< 1.1$ a weak solution occurs. There are weak shock waves in either flow and both flows remain supersonic. When the back pressure ratio is $p_p/p_{02} = 1.12$ a strong solution appears [2]. There is a weak shock wave in the primary flow and a strong shock wave in the secondary flow. The primary flow remains supersonic while the secondary flow becomes subsonic. The schlieren and the interferometric pictures of the weak solution are on Figure 2a and pictures of strong solutions are on Figure 2b. Let us focus on the weak solution. We can see from pictures, that the process of interaction of supersonic flows is more complicated due to the effects of viscosity.

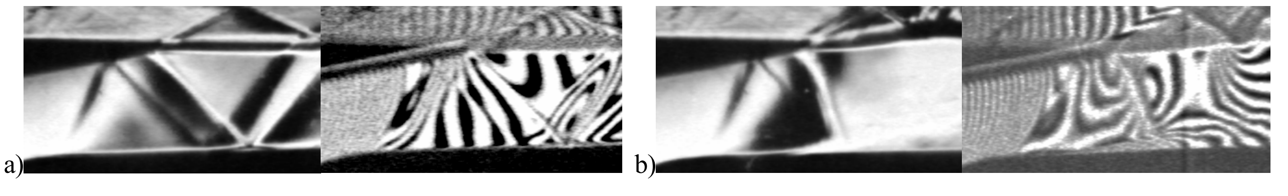

Figure 2: Schlieren and interferometric pictures of the interaction for $p_{01}/p_{02} = 4.09$, a - weak solution, b - strong solution.

The effects of viscosity can be explained with help of numerical solutions in Figure 3 and with help of scheme in Figure 1a. The whole process of mutual deflection of supersonic flows begins just ahead of the trailing edge by pressure levelling. The static presser is different on both sides of the trailing edge and its equalising ahead the trailing edge is allowed by subsonic part of boundary layers on both sides of the trailing edge. It caused a pressure rise in the secondary flow and the secondary flow separates. This flow separation yields compression wave signed (b1) - see Figure 1a. There is a pressure drop in the primary flow ahead of the edge and it gives a Prandtl-Meyer expansion signed (e1). As we can see on static pressure contours on Figure 3, the static pressures of both flows are equal just on the trailing edge. The flow angles downstream of the edge are matching and the pressure rises. It gives compression wave (b2) in the secondary flow and compression wave (e2) in primary flow.

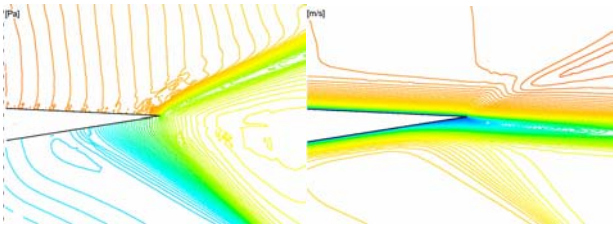

Figure 3: Numerical solutions - contours of static pressure and contours of velocity for $p_{01}/p_{02} = 4.09$.

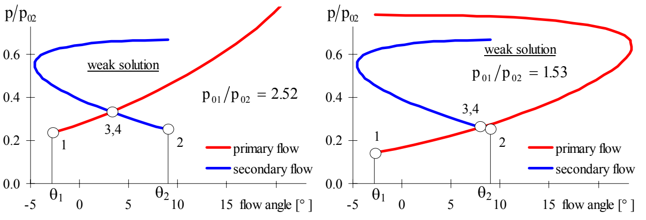

Figure 4: Theoretical solutions of interaction for regimes of $p_{01}/p_{02} = 2.52$ and $p_{01}/p_{02} = 1.53$.

The shear layers begin on the trailing edges and they propagate downstream. The shear layer is seen as a light area, the dark area is a wake which is formed by boundary layers streaming off both sides of the trailing edge and at the secondary flow separation. The wake is very relevant for mixing processes, because it separates both flows and so the mixing processes are delayed.
The influence of stagnation pressure ratio on the interaction of supersonic flows can be shown on regimes of the ejector on Figure 5. There is a regime of $p_{01}/p_{02} = 2.52$ on Figure 5a and a regime of $p_{01}/p_{02} = 1.53$ on Figure 5b. Theoretical solutions of these regimes are on Figure 4. The lower stagnation pressure ratio p_{01}/p_{02} causes: Less intensive shock wave (b) in the secondary flow, which changes into the expansion wave for $p_{01}/p_{02} = 1.53$. The expansion wave (e1) disappears and the compression wave (e2) becomes more intensive. The wake is shorter and thinner for low p_{01}/p_{02} , because static pressures of both flows are less different before interaction and secondary flow separation is negligible.

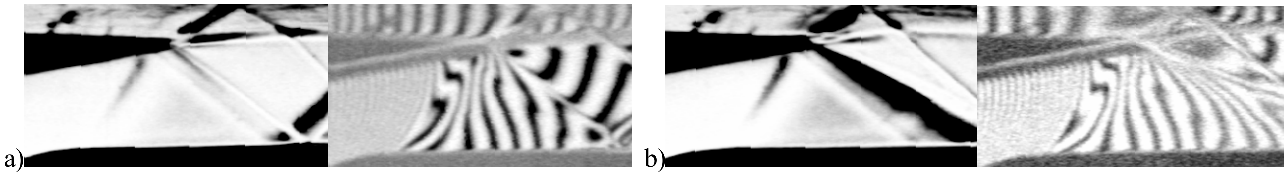

Figure 5: Schlieren and interferometric pictures of regimes of $p_{01}/p_{02} = 2.52$ and $p_{01}/p_{02} = 1.53$.

From results we can formulate recommendations for designing and operating of supersonic ejectors. To reduce losses due to shock waves from interaction of supersonic flows is necessary to design the trailing edge of the primary flow nozzle with very low angle. Of course, we can not make edge with zero angles and with zero thickness. To stifle the existence of the wake is needed to insure, that pressures of flows in front of the trailing edge are equal. We can do it in two ways. First we can design both nozzles with respect to the operating stagnation pressure ratio or change stagnation pressure ratio according to design of nozzles of an existing ejector.

CONCLUSION

The interaction of supersonic flows on the trailing edge of the primary flow nozzle of an ejector was studied by experimental, numerical and theoretical methods. The influences of back pressure ratio and stagnation pressure ratio on the interaction were presented. Recommendations for design of the entrance part of the supersonic ejectors and recommendations for operation of the supersonic ejectors were formulated. The optimisation problems of design and of operation of supersonic ejectors are very complex and these problems must be solved with respect of subsequent mixing processes in the mixing chamber.

References

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