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Development of air to air ejector for supersonic wind tunnel

Jan Kracík[1], Václav Dvořák[1a], Jan Kolář[1]

[1]Department of Power Engineering Equipment, Faculty of Mechanical Engineering, Technical University of Liberec, Studentska 2, 46117, Liberec, Czech Republic

Abstract. The contribution deals with the development of design of new conception of ejector with twelve primary annular nozzles arranged around the inlet part of the mixing chamber. The ejector is proposed to be used for propulsion of supersonic experimental wind tunnel with variable test section, which is now in development. The ejector is considered to be placed on outlet of this wind tunnel. The original design of the ejector has been modified to ensure its manufacturability. Software Ansys Fluent 14.0 was used for numerical verification of earlier work. The new design and dissimilarities of numerical results are presented in this work.

1 Introduction

The aim of this work is to design an air to air supersonic ejector for propulsion of aerodynamic wind tunnel which is situated in laboratories of Department of Power Engineering Equipment of Technical university of Liberec. The ejector will suck in air through experimental variable test section which is now in development. The scheme of arrangement of analogous wind tunnel is shown in figure 1.

In present work, the ejector was designed with twelve annular primary nozzles which are arranged around the inlet part of the mixing chamber. This conception is derived from optimal shape of ejector which was investigated by Dvořák in work [1]. The shape of the mixing chamber including the diffusor and declination of primary nozzles was optimized in this work. The aim of this work is to develop and modify the design of the ejector as to insure its manufacturability.

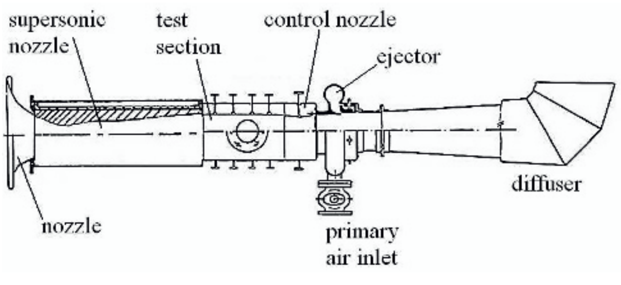

Figure 1. Supersonic wind tunnel with ejector propulsion [2].

Recently, there is a construction of test section in progress at the Department of Power Engineering Equipment. The design of the test section is based on work of Stupka et al. [3]. The ejector is designed with numerically computed efficiency approximately 25 %. It is also designed for reaching Mach number of 2.2 in the test section.

2 Methods

2.1. Development of ejector

The shape of the wall of the ejector optimized in work [1] is given by a normal cubic spline constructed through chosen points on the ejector wall. This design causes a rapid rise of static pressure in the mixing chamber and obtaining of high efficiency, which was estimated of about 25 %.

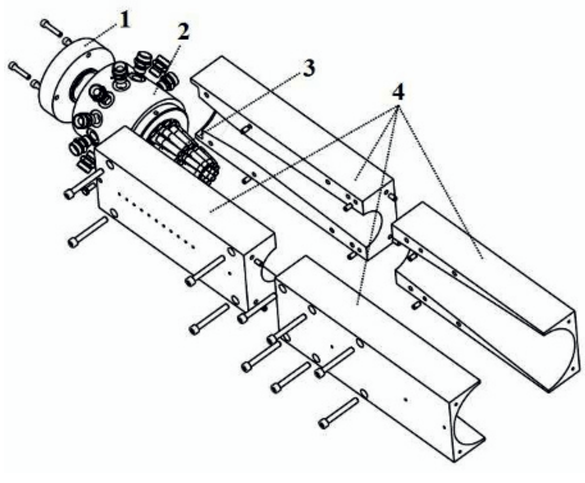

Figure 2. Main parts of ejector before compilation.
1 – inlet nozzle of secondary air ISA 1932, 2 – primary inlet – distribution of primary air, 3 – twelve primary nozzles,
4 – four parts forming the mixing chamber and the diffuser.

[a] vaclav.dvorak@tul.cz

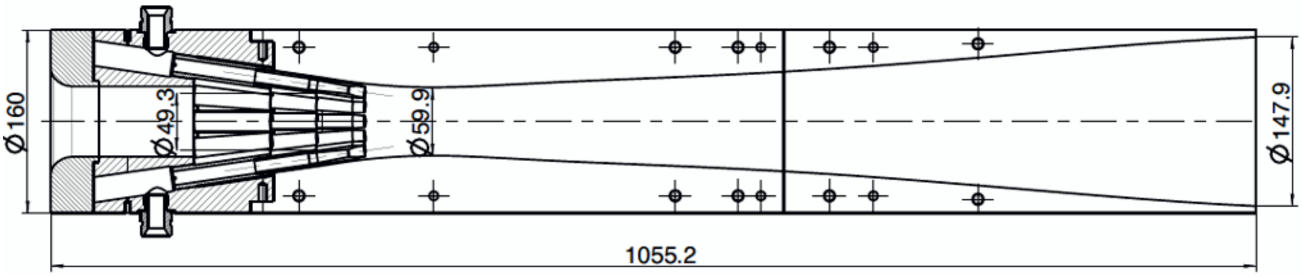

Figure 3. Central section of ejector for propulsion of supersonic wind tunnel with main dimensions.

To design a manufacturable construction of the ejector proposed by Kolar in work [2] and optimized by Dvorak in work [1], the whole ejector was divided into six main parts, which form body of ejector, twelve annular supersonic nozzles, twelve ½“ adapters for driving air intake and several assembly components (bolts and pins). Each of nozzles is mounted from three parts threaded together. The most important parts of ejector are shown in figure 2.

The whole ejector with main dimension is obvious from figure 3. The total length of ejector is 1.0552 (m), both height and width are 0.16 (m). The diameter of sucking part of ejector was determined as D_2 = 49.3 (mm) and is strongly dependent on final assembling of primary nozzles. The nozzles are considered replaceable. The declination of nozzles is of 8.2°, thus, the reversal flow in the centre of the ejector is almost eliminated. Resulting construction should allow controlling of flow in each nozzle. Thus the ejector will be able to operate with various counts of primary nozzles and to obtain different regimes of the ejector.

The diameter of narrowest part in mixing chamber, the ejector throat, is D_3 = 59.9 (mm). The length of inlet part of ejector was originally 120 (mm), but it was extended to 196 (mm) (including inlet nozzle 233.2 mm) due to construction reasons. The length of mixing chamber with diffuser was reduced to 822 (mm) from 1200 (mm), because the static pressure rise was negligible in the outlet part of the ejector. Easier manufactory, cost savings for material and fact that the outlet part of diffuser is not interesting for research investigating were the others reasons to shorten the ejector. This shortening caused contraction of ejector outlet diameter D_4 from 152.7 (mm) to 147.9 (mm).

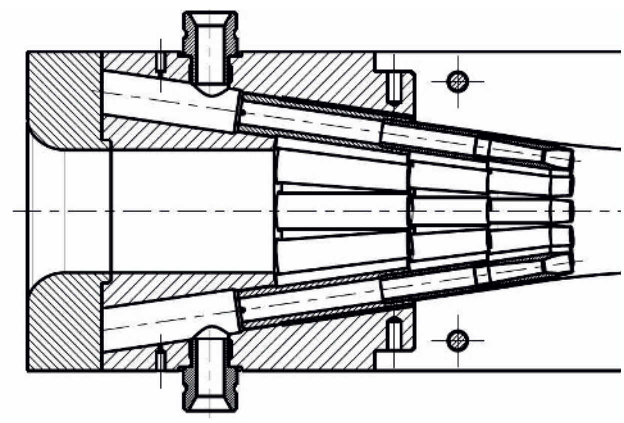

Figure 4. Detailed view on the inlet part of the ejector.

The inlet part of the secondary air stream is based on ISA 1932 to allow later measuring of mass flow rate of sucked secondary air stream. The nozzle was designed according to standard [4].

The inlet part of the primary air stream is designed to allow later exchange of any of twelve primary nozzles. It will also allow us to switch off any of the primary nozzles and investigate mixing and performance of the ejector with different counts of the operating primary nozzles and to obtain various regimes of the ejector. Due to these reasons, it was necessary to slightly modify original design. Supersonic nozzles consist of three parts to achieve required shape of inner channels and to avoid intersection of outer surfaces of the nozzles. The primary nozzles are designed with area ratio A_{exit}/A_{throut} = 2, which provides exit Mach number of M_1 = 2.2. The detailed view of the inlet part holding primary nozzles are shown in figure 4.

The part which is most difficult to manufacture is the ejector body, which includes both the mixing chamber and the diffuser. Eventually, a design of this part was chosen to be manufactured from four pieces. It was very important to keep optimized shaped of the ejector channel obtained in work [1]. This part is equipped with sixteen static pressure taps. Position of them was chosen based on results of numerical computation presented in the next paragraph.

2.2. Numerical model

Software Ansys Fluent 14.0 was used for computation of flow in the ejector. The geometry of computation domain including boundary conditions is obvious from figure 5. The computational model was three-dimensional and it included only one primary nozzle. This model was created as one twelfth of the real model defined by to plane forming an angle of 30°. These planes, which intersected with each other in the ejector axis, were the symmetrical planes.

The setup of the solver was the same as in work [1] for later comparison of the results. The *pressure based* solver was used because of better convergence. This solver solves the governing equations segregated from one another. For more information, see documentation [8]. There was a turbulence model k-ω SST chosen for computing of flow. This turbulence model was used and recommended for computing of flow in supersonic ejectors in several works. E.g. Bartosiewicz et al. used this model in work [5], Simak in work [6] and Kolar and Dvorak in work [7].

We used pressure inlet boundary conditions in the inlets of the model. Absolut Stagnation pressure p_{01} = 400 (kPa), stagnation temperature T_{01} = 300 (K) and turbulence intensity 10% were specified in the inlet of primary air stream. Absolut stagnation pressure p_{02} = 70 (kPa), stagnation temperature T_{02} = 300 (K) and turbulence intensity 30% were set up at the inlet of the suction, i.e. at the inlet of secondary air stream. As the outlet boundary condition was used absolute back pressure, set as p_b = 100 (kPa). The higher turbulence intensity for inlet of suction part is derived from assumption, that the flow behind the test section is quite unlevelled.

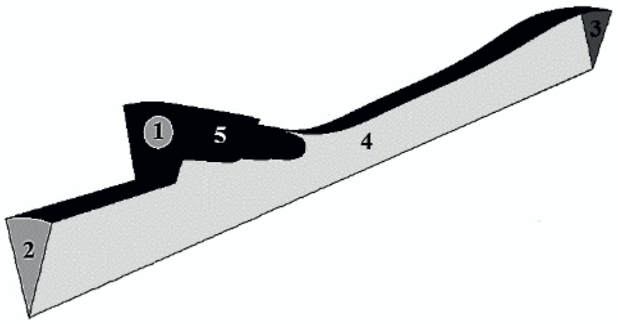

Figure 5. Computational domain with boundary conditions. 1 – primary inlet, 2 – secondary inlet, 3 – outflow, 4 – symmetry, 5 – wall of the primary nozzle.

3 Results

An analysis of flow in resulting ejector is in figure 6. There are contours of turbulent kinetic energy, Mach number and static pressure in the picture. Curves of the static pressure and the mass weighted turbulent kinetic energy along the ejector axis are carried out into the diagram. The initial region of mixing is characterised by the existence of the unaffected secondary stream, slow mixing and practically constant static pressure. In work [1], the initial region ends in the narrowest cross section of the ejector – in the ejector throat.

In contrast with original work [1], the initial region of mixing, characterised by slow static pressure rise, is terminated by a normal shock wave in our case. This strong shock wave, which is called terminal shock wave according to work [šanghai], is well visible on static pressure course and static pressure contours in figure 6. Here, the static pressure begins to rise rapidly, while the free shear layer (the mixing layer) does not reach the mixing chamber centre. In this case, the unaffected secondary stream still exists and vanishes later. Compared to the mixing with the only one primary nozzle placed in the axis of the ejector, the end of the mixing, i.e. the end of the main region of mixing and the beginning of the diffuser section cannot be practically identified. Reversal flow in the centre of the mixing chamber is almost removed.

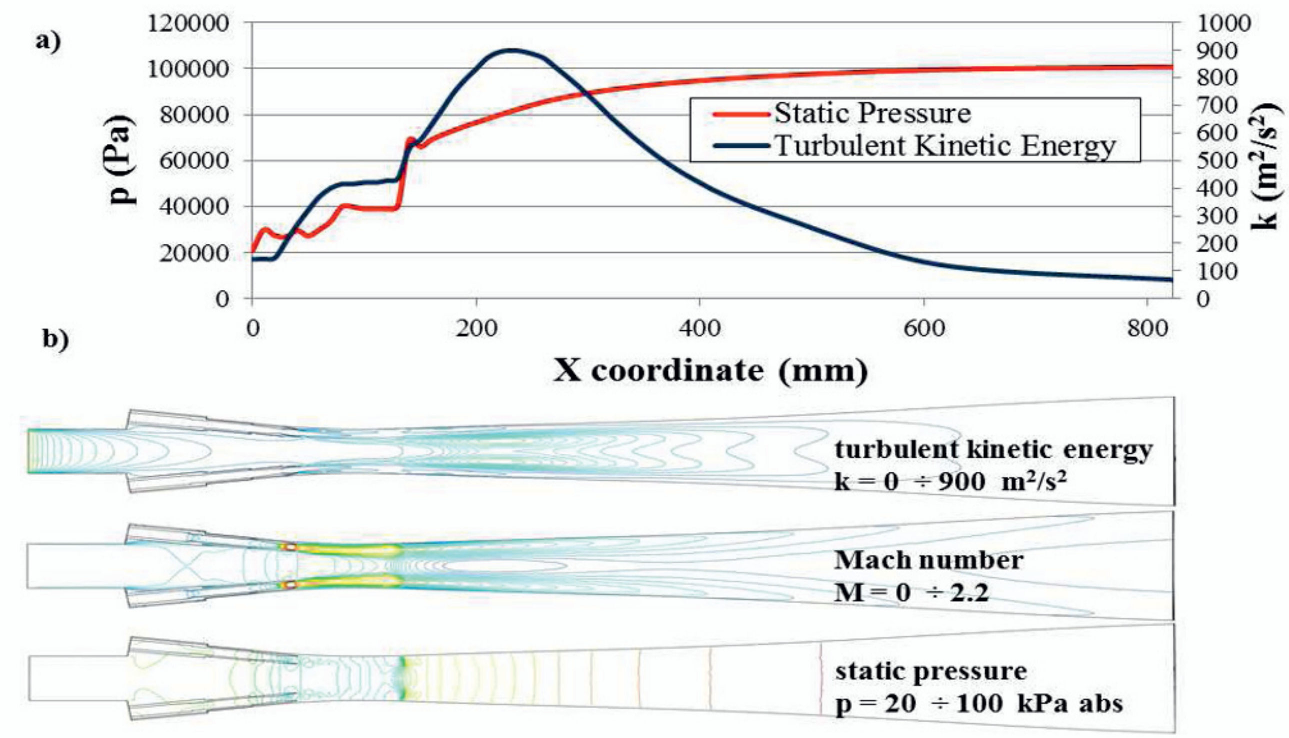

Figure 6. Analysis of flow in the mixing chamber and diffuser. Curves of the static pressure and mass weighted turbulent kinetic energy throughout the mixing process a). Contours of turbulent kinetic energy, Mach number and static pressure b).

4 Conclusions

A construction of a new concept of ejector was designed for propulsion of experimental supersonic wind tunnel with variable test section that is in development at the Department of Power Engineering Equipment at the Technical University of Liberec. It was designed inner shape of mixing chamber with diffuser based on work [1]. The twelve annular primary nozzles ensure intake of primary (driving) air. It is considered independent control of each nozzle and their interchangeability. Because of manufacturing and subsequently mounting, the geometry around nozzles area was slightly modified in comparison with work [1]. For this reason, numerical computation in software Ansys Fluent 14.0 was performed. There was found a reversal flow in the mixing chamber and thus we can expect a lower efficiency than in case estimated in work [1] by Dvorak.

Acknowledgment

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