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INVESTIGATION OF THE PRESSURE DISTRIBUTION IN 2D ROCKET NOZZLE WITH MECHANICAL SYSTEM FOR TVC

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Abstract

In this paper a new physical model of the gas flow through the 2D nozzle with the tilted obstacle in exit section is introduced and studied. Experimental investigation on the 2D full span model in the supersonic indraft tunnel, which include over three hundred tunnel runs are presented. Variable geometric parameters were: nozzle shadow area, obstacle-nozzle wall angle, obstacle-nozzle gap and nozzle area ratio. In the conclusion, the results are discussed and the suggestions for the future work were presented.

1. Introduction

A special group within the rocket guide systems are the gasodynamic systems. They operate on the basic of direction and intensity change in the rocket motor thrust. This paper is dedicated to the performance analysis of the thrust vector control (TVC) system by means of stream deflection i.e. the supersonic stream is deflecting by using a mechanical obstacle. As a result of introducing this obstacle the boundary layer is separated and the pressure along the nozzle and obstacle is redistributed, whereby the direction and intensity of the thrust are changed. The common name of this system is the mechanical system for TVC with unmovable nozzle.

Determination of the system nozzle-obstacle performances is linked with a through knowledge of the disturbed zone parameters in the nozzle. This paper deals with the above mentioned matters in view of the research work carried out by our group on problems of pressure distribution along the nozzle walls.

2. Description of the investigations

Generally speaking, experiments with 2D model were done to discover the real physical model and

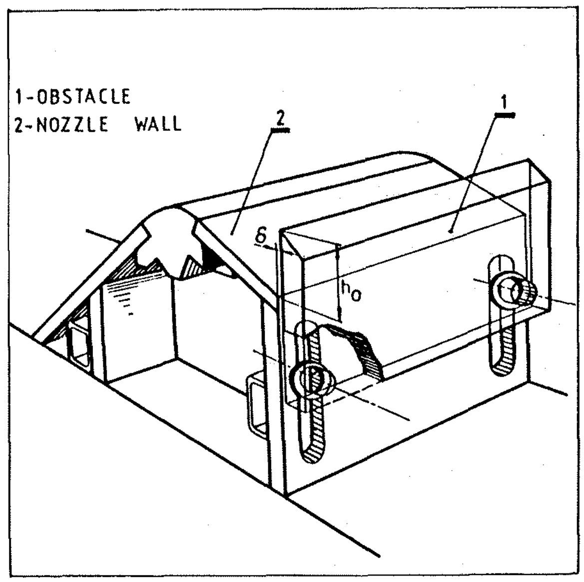

Figure 1.

to measure all necessary parameters in nozzle disturbance zone (separation point, pressure distribution on the wall, and pressure distribution along the front and back side of the obstacle).

Experiments took place in a supersonic indraft type wind tunnel, in which working section a full span 2D model was set up (shown on the Fig. 1). On these installation, so called **cold investigations** were made (e.g. stagnation conditions were p=1 bar T_o=288°K).

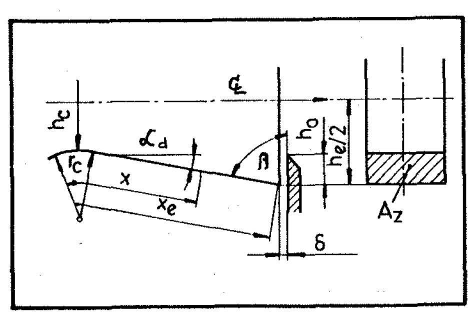

Figure 2.

During the test, pressure distribution was measured trough the characteristic zones of the nozzle, and a research of the flow field was done by visualization with the Schlieren photographs. The whole experimental investigations including data processing and the wind tunnel control were done by PDP 11/10 computer, and on S model Scanivalves with Druck 5 psi pick ups.

Over three hundred tunnel runs have been done with this experimental set, on which the following geometric parameters has been varied (according to the Fig. 2):

- **nozzle shadow area, A_z** (height of the obstacle)
- **obstacle-nozzle wall angle, β**
- **obstacle-nozzle gap, δ**
- **nozzle area ratio, ε**

3. Experimental results and discussion

Experimental investigations showed that due to the obstacle in exit section of the nozzle, **gas wedge** is placed inside the nozzle (recurrent flow district), and as a consequence, nozzle **wall separation of the flow** occurred, which change the pressure distribution and a whole flow picture.

Experimental results were normalized and shown in two ways: correlated through the geometric parameters of nozzle-obstacle, and correlated trough the nozzle fluid flow parameters.

On Fig. 4, Fig. 5 and Fig. 6 pressure distributions in the separated zone of the nozzle wall were shown as a function of geometric parameters of the nozzle-obstacle (according to Fig. 3). This results show that the same globas effects of the phenomena (wall pressure rise, width of the separation zone, etc.), can be achieved by the different combinations of the geometric parameters of nozzle and obstacle. Conclusions which can be made

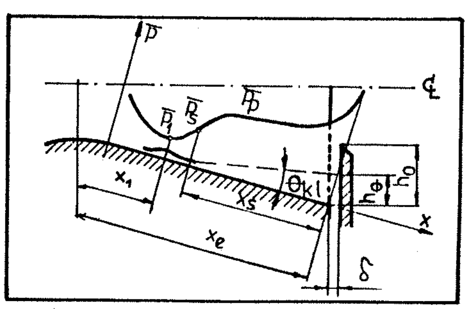

Figure 3.

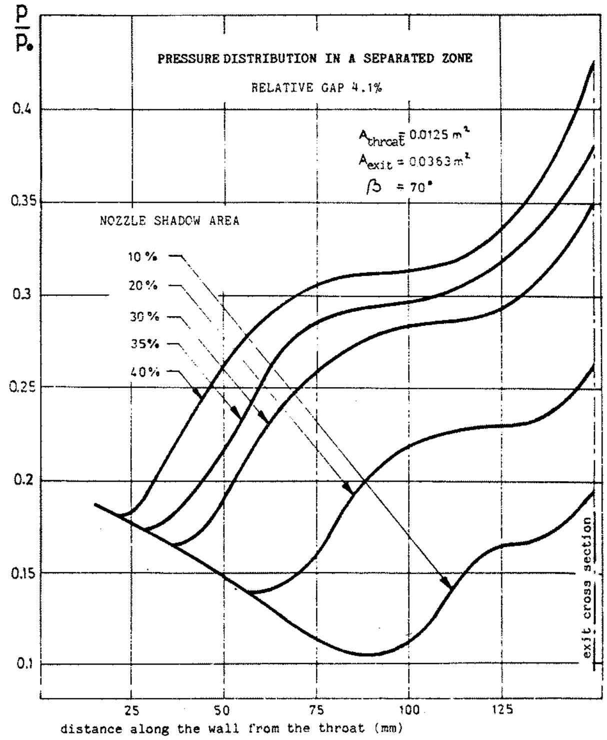

Figure 4.

from this results, may be summarized as follows:

- The increase of disturbance zone is proportional to the nozzle shadow area (height of the obstacle)
- The influence of gap and nozzle-obstacle angle is similar, i.e. their increasing is connected with nozzle disturbance zone width decreasing
- Main characteristic of the disturbance zone is the mean pressure value, so called **plateau pressure**, defined by the equation:

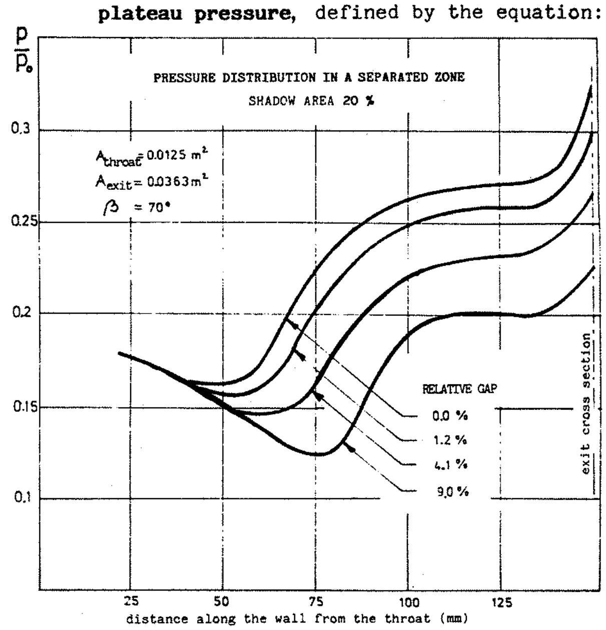

Figure 5.

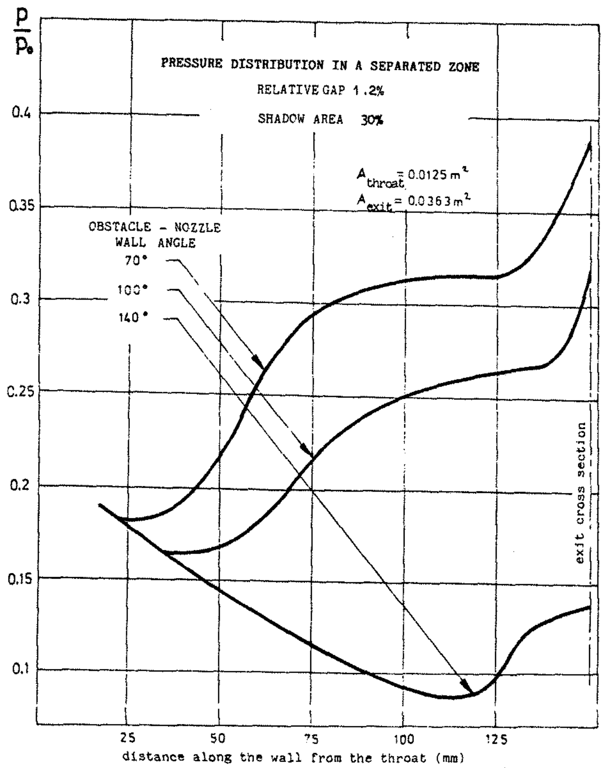

Figure 6.

$$p_p = \frac{1}{x_e - x_1} \int_{x_1}^{x_e} p\, dx$$

On Fig. 7 to Fig. 11 results were shown as a function of nozzle fluid flow parameters. This results are very interesting because they show that the parameters of the separation zone are function of the characteristics of a nozzle in which they are achieved (e.g. nozzle area ratio, local Reynolds and Mach number, thickness of the boundary layer, etc).

From the given diagrams the following important conclusions can be reached:

- The **position of the separation point** can be expressed as a function of disturbance (function of nozzle shadow area, nozzle-obstacle gap and nozzle-obstacle angle)
- The **plateau pressure** in a separated zone is not a function of the disturbance, but a function of the flow parameters in the point at the nozzle wall just in front of the starting separation (point 1)
- The **angle of gas wedge** is found to be a universal function of pressure coefficient C_p (defined and showed in Fig. 11)

Based on our experimental work (measured pressure distribution and Schlieren photographs) we introduce a **new physical model** of the studied phenomena (shown on Fig. 12). The main characteristics of this model are:

1. In disturbance zone the **gas wedge** (6) and **separation region** are established. The shape and

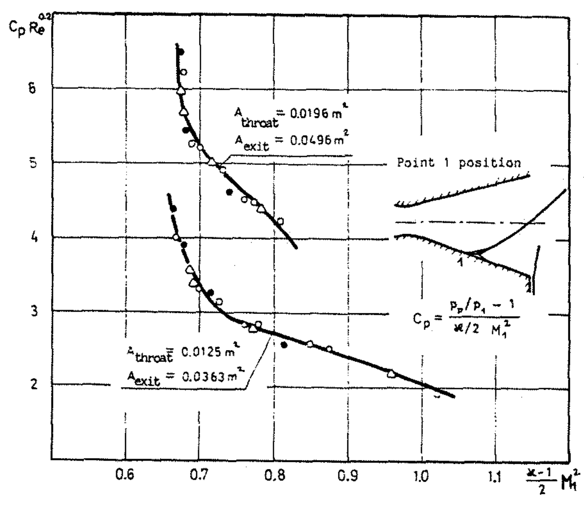

Figure 7.

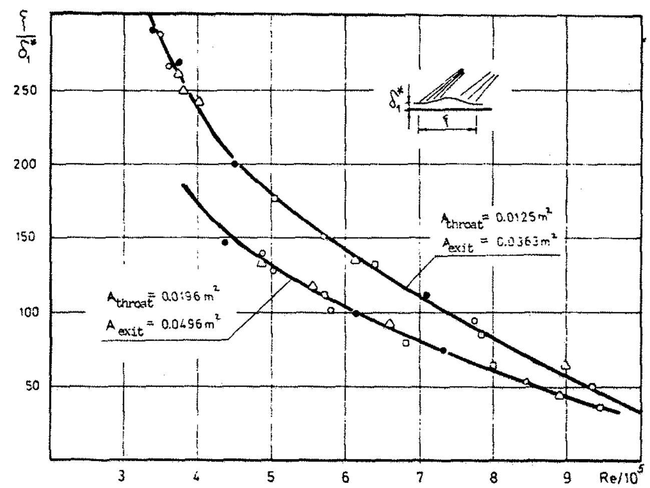

Figure 8.

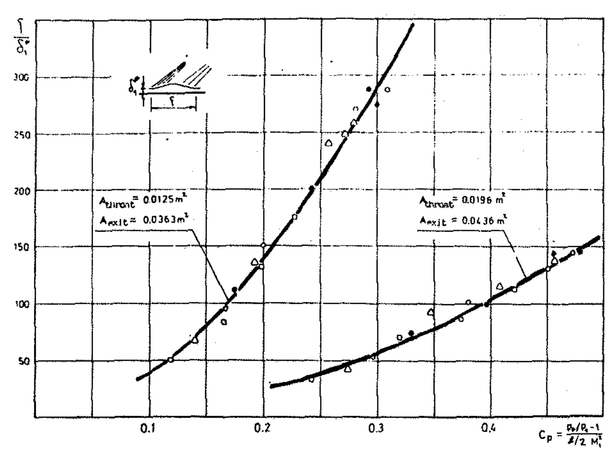

Figure 9.

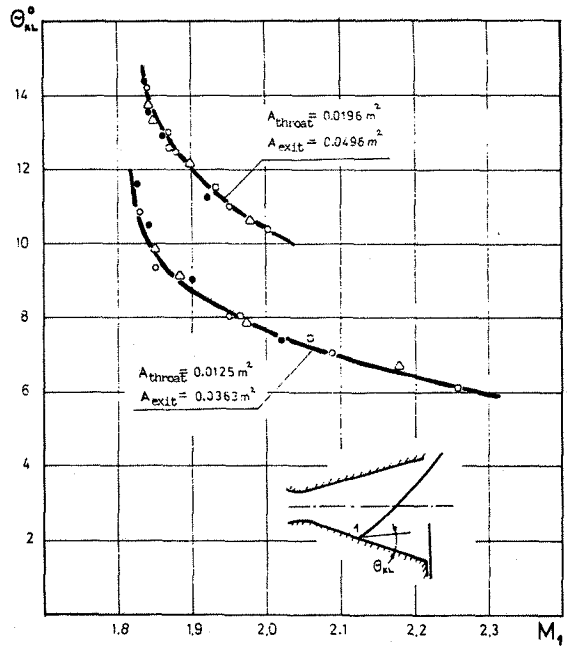

Figure 10.

the magnitude of the gas wedge is not attached to the top of the obstacle (like in the case of 1D models of forward facing steps studied by some authors). The mean value of pressure in this zone is approximately equal to **plateau value.**

2. The **lambda bubble** (5) around the separation point is the source of **compressible** (4, 2) and **expansion shock waves** (3). The main **oblique shock wave** (1) has been caused by gas wedge. Very strong **normal shock wave** (7, 9) has been established in front of the tilted obstacle.

3. Mass transport phenomena in disturbance zone was demonstrated through the **mixture layers** between gas wedge, main stream and mass loses through the nozzle-obstacle gap.

4. Pressure distribution along the obstacle is not a simple one, and thereby our next paper will be all concerned to that problem. At this moment it can be said that pressure distribution on the front side of the obstacle is found to have two extremes, i.e. one maximum near the obstacle hub (approx. 0.8 h_o), and one minimum near the obstacle root (approx. 0.2 h_o).

5. The physical model and experimental work leads to mathematical expressions in the form:

- separation point:

$$\bar{x}_s = 1.43\, f(\beta)\, \bar{A}_z^{\,0.35}\,(1+\bar{\delta}^2)^{-22}$$

$$f(\beta) = 1-0.47(\beta-1.22)^{1.774}(1+\bar{\delta})^{9.85}$$

This equation is valid for:

$$0.1 < \bar{A}_z < 0.3 \qquad 0.0 < \bar{\delta} < 0.09$$

$$1.22 < \beta < 2.44$$

- plateau pressure:

$$\frac{p_p}{p_1} = 1 + \frac{a}{(M_1 - M_{cr})^n}$$

with: $M_{cr} = 1.73$ $\quad a = 0.378 \quad n = 0.25$

- mean pressure along the front side of tilted obstacle:

$$\frac{p_f}{p_1} \cong 1.8 \div 2.1$$

7. Conclusions

Presented investigations show the complexity of flows through the 2D nozzles with mechanical system for TVC. Experimentally obtained equations were applied to the numerical modeling and for computer program of pressure integration and calculation global effects of TVC system (side force and thrust losses). Numerical testings of wide range

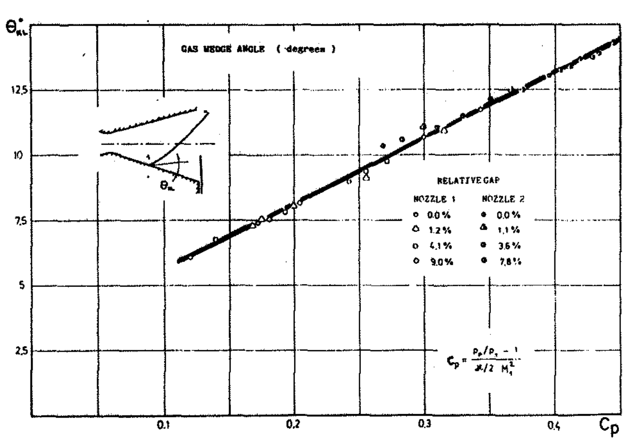

Figure 11.

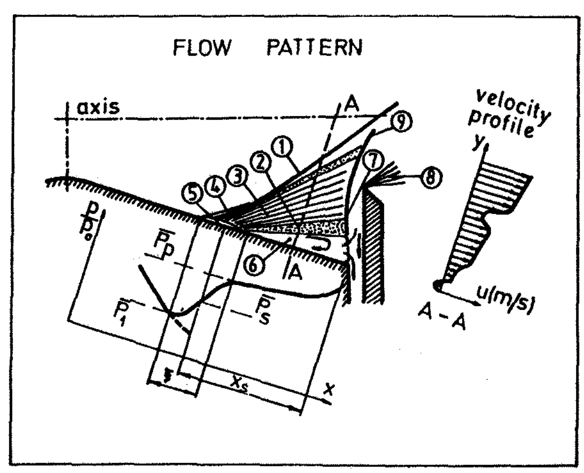

Figure 12.

2D configurations (nozzle-obstacle), show satisfactory results (within the reasonable engineering limits).

Our future work on 2D nozzles with mechanical system for TVC will include studying and testing the system in real gas flow conditions, which means that main concern will be placed on the following problems:

- so called "hot conditions", i.e. gas flows with high stagnation values of pressure and temperature
- experiments with the flow of chemically reacting gas mixtures and gas-particle mixture
- experiments in the case of nonisotermic nozzle walls

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