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Obtaining supersonic airflow in transonic wind tunnels and sliced wall perforation in the test section

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By an apropriate modeling of partially opened walls of a wind tunnel, Mach number in the test section can be increased even after air stream sonic velocity has been achieved. This is achieved by conducting air stream to the test section chambe. For conventional supersonic wind tunnels, supersonic Mach numbers can be obtained by placing the supersonic nozzle in front of the test section, the contour (shape) of which is being characteristic for each Mach number. Change in supersonic nozzle contour is very small for a Mach number close to one, thus making small changes in a Mach number for the closed test section impossible. Additionally, after taking into consideration more difficult compensation of the boundary layer in the test section for these small changes in the gradient of Mach number (when M≈1), a need for air removal from the test section into the test section chamber of a transonic wind tunnel becomes even more pronounced.

Key words: **transonic wind tunnel, test section, supersonic flow, Mach number.**

Used acronyms and symbols

M – Mach number
m – (air) mass flow
A – cross section of a supersonic nozzle (first throttle)
A_M – surface area the model, frontal to the flow direction
H – height of the transonic wind tunnel test section
$3D$ – three-dimensional test section
$2D$ – two-dimensional test section

Introduction

BY an apropriate modeling of partially opened walls of a wind tunnel, Mach number in the test section can be increased even after air stream sonic velocity has been obtained, by conducting air stream to the test section chamber. This is of great significance. For conventional supersonic wind tunnels, supersonic Mach numbers can be reached by placing the supersonic nozzle in front of the test section, the contour (shape) of which is being characteristic for each Mach number. Change in contour of supersonic nozzle is so small for Mach numbers close to unity, that a small change in a Mach number for the closed test section in this range of M numbers is impossible. This task is also made difficult by the level of necessary boundary layer compensation in the test section for these small changes in the Mach number gradient. Because of these reasons, Mach numbers close to one have to be obtained by suction of a defined mass of airflow to the test section chamber. This has to be done no matter if the supersonic nozzle is used or not.

There is a difference in air suction (to the test section chamber) effects for subsonic and supersonic velocity ranges. In the subsonic range, difference in removed air mass influences the Mach number distribution in the direction along the air stream, whereas for the supersonic range it influences also the realization of an appropriate Mach number.

Achieving a supersonic airflow in transonic wind tunnels

In classical supersonic wind tunnels, supersonic airflow is being obtained by an appropriate contour of the supersonic nozzle. The part of this nozzle down the sonic line flow direction is predetermined by the condition that all Mach waves initiated in the part up the air stream have to be eliminated by an approppriate curvature of the wall elements in order to provide paralel air stream in the test section. The analysis of the nozzle shape shows that expanding air flow in the nozzle passes through an imaginary opened wall (parallel to the central line - geometrical axis of the nozzle) with perpendicular velocities reaching the maximum in the proximity of the saddle point of the nozzle conture. This is shown in Fig.1.

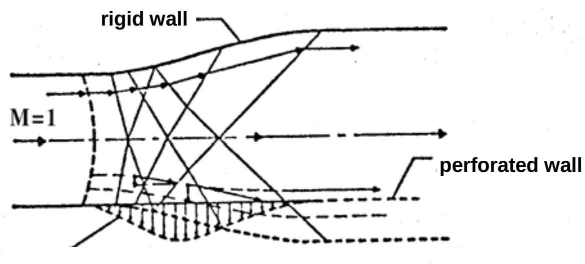


Figure 1. Comparison between the classical nozzle and the nozzle with partially opened walls

The same air flow would be obtained in a case when partially opened walls are realised with controlled local air

[1)] Vidikovaćki venac 41, 11030 Belgrade suction through these walls, as in the case of airflow in the test section with the supersonic nozzle.

When smooth supersonic circulation is achieved in the transonic test section by means of the sonic partially opened nozzle, airflow distribution through walls has to be accuratley controled by simulating the same distribution of the perpendicular velocity component as for the conventional supersonic nozzle.

The distribution of the perpendicular velocity component along the partially opened wall can be calculated by the method of characteristics. Therefore, it is possible to define theoretically the ratio of opened surfaces in order to establish nonreflecting airflow in the wind tunnel test section. Conditions for establishing accurate airflow in wind tunnels with partially opened walls are less critical; possibilities for eliminating Mach waves are much greater and so are the possibilities for obtaining a parallel air stream. This simplifies the distribution of wall perforations - slits in the area where uniform supersonic air flow is to be obtained.

Although the perforated nozzle provides a considerable advantage because of simplicity of necessary equipment (no need for a precise supersonic nozzle) it cannot be used in a wide range of Mach numbers, but only in a very narrow range above *M*=1. For realisation of higher Mach numbers suction of larger air masses is required. For isentropic airflow there is a strong correlation between the air mass removed from the air stream bulk in the nozzle with partially opened walls and the necessary change in the cross section of the supersonic nozzle in order to provide a particular Mach number, i.e. $dm/m=dA/A$. Consequently, on the basis of eq. (1) it is possible to define necessary air suction from the airflow bulk for given Mach numbers.

$$\frac{A}{A-A_M}=\frac{1}{M}\left[\frac{5}{6}\left(1+0,2M^2\right)\right]^3 \quad (1)$$

The solution of eq. (1) is shown in Fig.2.

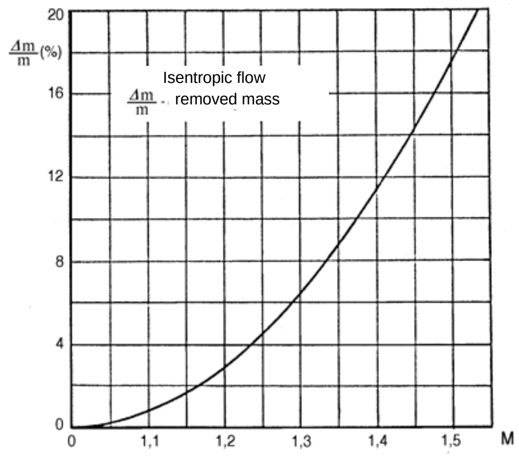


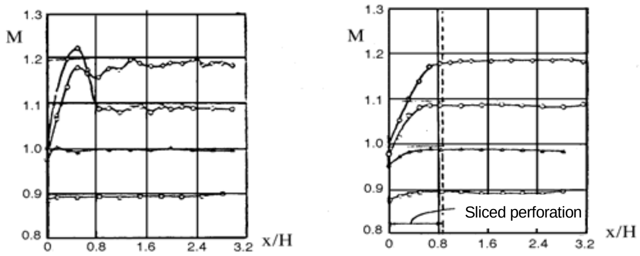
Figure 2. Removed air mass as a function of Mach number in the nozzle with partially opened walls

In order to obtain Mach number M=1.1 it is necesary to remove only 0.8 % of air mass from the air stream bulk through partially opened walls. This value rises to 3 % for M=1.2, and to 11.5 % for M=1.4. Since air cannot loose much of its kinetic energy as a consequence of whirlpool formation in the test section chamber and decreased efficiency of a diffusor, it is not possible to remove huge air masses. Experimental results [1], show that only relatively small transonic wind tunnels with the height of t

he test section $H \le 300$ mm can achieve M=1.25 and slighly higher vlues. All larger transonic wind tunnels must be also equipped with the clasical supersonic nozzle to realise M>1.2.

Slice - perforated section of walls of transonic wind tunnels

In 1954 a study was carried out in the AEDC in the transonic model wind tunnel with perpendicular perforations-slits and the ratio of opened surfaces of 22.5 % aiming to define a configuration of perforated walls which gives uniform airflow in the wind tunnel test section [1]. The study showed that, for subsonic airflow (subsonic Mach numbers), uniform air stream in the test section was easy to be obtained with clasical configuration of perforated walls, as shown in Fig.3a, whereas for supersonic flow, (supersonic Mach numbers), on the other hand, nonuniformity in airflow was observed. Very strong overexpansion observed at the surface of transition from full to perforated walls at supersonic Mach numbers completely disturbed airflow in the test section since this initial wave disturbance was only gradually eliminated by perforated walls.



a) Uncontrolled expansion (no perforated porosity)

b) Controlled expansion (with perforated porosity of all four walls)

Figure 3. Mach number distribution in the perforated test section with uncontrolled and controlled expansion [1]

In order to continuously eliminate this initial overexpansion, the AEDC, for the first time, applied the concept of section of sliced perforation, in literature frequently called the stream (flow) stabilizer or the sonic nozzle, i.e. partial perforation of a certain shape (Fig.4). This very simple shape of perforated wall(s) change the character of Mach number change to a very smooth distribution, as shown in Fig.3b.

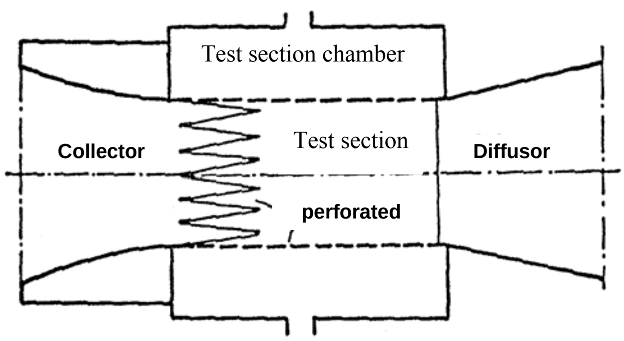


Figure 4. Schematical representation of the perforated test section with the slice - perforated section for control of supersonic expansion

The shape of sliced perforation is being approximately determined on the basis of geometric parameters (i.e. size)

of the perforated wall and its final shape has to be verified in experiment, i.e. the shape has to correspond to optimum conditions of uniform distribution of Mach number in the supersonic velocity range.
Geometric presentation of sliced perforation is shown in Fig.5.

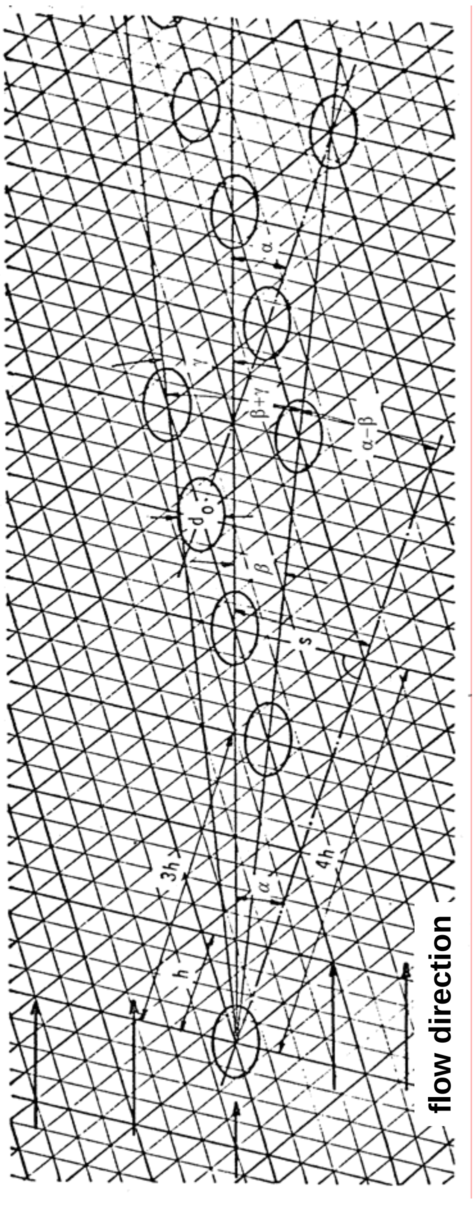


Figure 5. Basic shape of sliced perforation with a tilt angle of 60° and with shown orientation angles towards flow direction

It has to be underlined that the best results have been shown by a sheared shape of perforation, as seen in Fig.5, where every fourth slit on the perforated wall is in air stream direction. In that way interferring influence of slits is reduced and their efficiency is increased along with reduced flow resistance. The length of the sliced section depends on the width of a wind tunnel in the case of the two-dimensional (2D) test section, and on the width and height in the case of the three-dimensional (3D)test section. It is evident that, the size of perforations changes linearly from zero, at the beginning, to full perforation at the end of the sliced section. Usually the length of the sliced section is around ½ and ¾ of the height of the test section. For reduced dimensions of the wind tunnel test section this length is commonly up to 1.0 H.

When, for supersonic airflow a conventional supersonic nozzle is used the problem of obtaining uniform flow is not that much pronounced.

However, transition from the rigid walls of the supersonic nozzle to the partially opened walls of the test section provides different conditions for the formation of a boundary layer which, with a slight inaccuracy in the conture of the test section nozzle, can generate irregular distribution of Mach number in the test section even when the supersonic nozzle is used. Voluminous experimental work led to the conclusion that in this case sliced perforation, i.e. sliced porosity, should be used for realising uniform distribution of Mach number in the wind tunnel.test section. The experimental results obtained in the AEDC show that this test section configuration forms uniform airflow field even for M=1.6 [1], as shown in Fig.6.

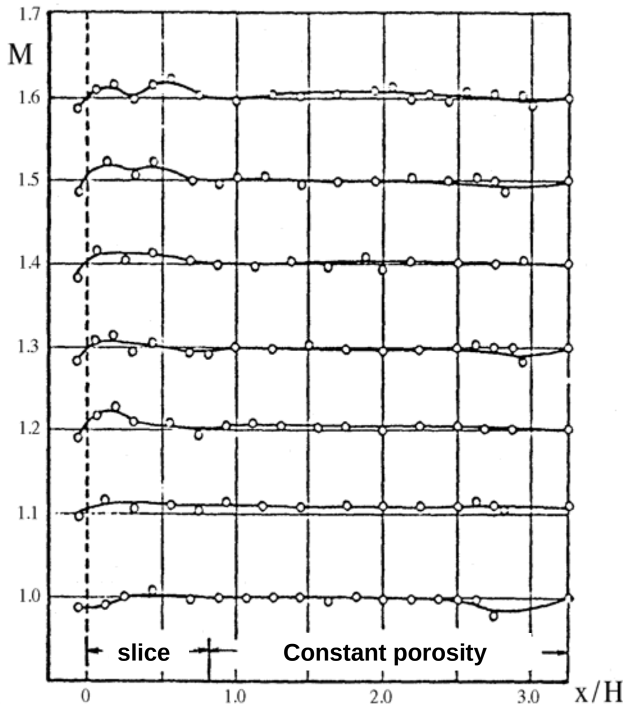


Figure 6. Mach number distribution in the AEDC transonic wind tunnel; height was 4.88m, with a supersonic nozzle, test section walls were parallel and the perforation tilt angle was 60° [1]

Conclusion

There is a difference in air suction (into the test section chamber) effects for subsonic and supersonic velocity ranges. In the subsonic range, difference in removed air mass influences the Mach number distribution in the direction along the air stream, whereas for the supersonic range it influences, in addition, obtaiming appropriate Mach number.

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Uspostavljanje supersoničnog strujanja vazduha u transoničnim aerotunelima i kriškasta sekcija perforacije zidova transoničnog radnog dela

Pogodnim oblikovanjem parcijalno otvorenih zidova aerotunela, Mach-ov broj u radnom delu može se povećati i nakon postizanja sonične brzine odvođenjem mase struje vazduha u komoru radnog dela aerotunela. Kod konvencionalnih supersoničnih aerotunela supersonični Mach-ovi brojevi mogu se uspostaviti postavljanjem supersoničnog mlaznika ispred radnog dela, koji ima određenu konturu za svaki Mach-ov broj. Promena konture supersoničnog mlaznika je vrlo mala u blizini Mach-ovog broja jednakom jedinici konture supersoničnog mlaznika je vrlo mala u blizini Mach-ovog broja jednakom jedinici te je nemoguće u zatvorenom radnom delu ostvariti vrlo male promene Mach-ovog broja u ovoj oblasti. Ako se pri tome uzme u obzir i otežana kompenzacija graničnog sloja u radnom delu pri ovim malim promenama u gradijentu Mach-ovog broja u blizini Mach-ovog broja jednakom jedinici, potreba za odvođenjem vazduha iz radnog dela u komoru radnog dela u komoru radnog dela transoničnog aerotunela je još eksplicitnije izražena.

Ključne reči: **transonični aerotunel, radni deo, supersonično strujanje, Mach-ov broj.**

Устанавливание сверхзвукового потока воздуха в околозвуковых аэродинамических трубах и пластина перфорации стен околозвуковой испытательной секции

Подходящим моделированием частично открытых стен аэродинамической трубы, число Маха в испытательной секции может увеличится и после достижения звуковой скорости отбором массы потока воздуха в камеру испытательной секции аэродинамической трубы. У привычных сверхзвуковых аэродинамических труб сверхзвуковые числа Маха могут быть определены установлением сверхзвукового сопла перед испытательной секцией, у которой уче определенный профиль для каждого числа Маха. Изменение профиля сверхзвукового сопла очень маленькое вблизи числа Маха=1, из-за чего в закрытой испытательной секции невозмочно установить такие очень маленькие изменения числа Маха в этой области. Если при этом взять во внимание и осложненную компенсацию пограничного слоя в испытательной секции при этим маленьким изменениям в градиенте числа Маха вблизи М=1, нужда для отбора воздуха из испытательной секции в камеру испытательной секции околозвуковой аэродинамической трубы выражена еще более выразительно.

Ключевые слова: околозвуковая аэродинамическая труба, испытательная секция, сверхзвуковой поток, число Маха.