UDK: 533.6.071/.072:533.69.04
COSATI: 14-02, 01-01

Analysis of the necessary air suction from the test section of a transonic wind tunnel

Borivoj Blizanac, PhD (Eng.)[1]

In the closed test section of a wind tunnel (with parallel walls) effective surface area of the cross section is getting smaller in the direction of the air stream. This is the result of the continuous increase in thickness of boundary layer along the walls of the test section of a wind tunnel. As the consequence of this effect the sonic velocity will be established at the end of the test section, although the velocity of the air stream in the beginning section of the test section is still significantly smaller than M=1. In order for sonic velocity in the empty test section with the closed walls to be established, condition that walls are divergent has to be met. This condition depends on parameters such as perforation of the walls, Reynolds and Mach numbers. Similar phenomena are present in the test section with partially opened walls when there is no auxiliary suction of air in the test section chamber.

For the uniform air flow in the test section of a wind tunnel with perforated walls to be achieved it is necessary to perform auxiliary suction of the air from the test section to the chamber of the test section.

Key words: **wind tunnel, aerodynamic testing, transonic flow**

Symbols

M – Mach number
L – length of a wind tunnel test section
H – height of a wind tunnel test section
K_p – openness coefficient of a wind tunnel test section walls
M – mass flow of air in a test section of a wind tunnel
Δm – air mass removed from test section to a chamber of a test section of a wind tunnel

Introduction

IN the closed test section of a wind tunnel with parallel walls, effective cross section is gradually getting smaller in the direction along the air flow as consequence of the continuous increase in thickness of the boundary layer along the walls of the test section. In result, test section will be muffled, i.e. sonic velocity will be established at the end of the test section, although the velocity of an air stream in the beginning section of the test section is still by far lower than $M = 1$. In order for the sonic velocity to be achieved, necessary condition that walls are divergent has to be met. Typical values for the angle of divergence of the test section (with circular cross section) is approximately $(5 \div 7)°$. This value depends on parameters such as wall perforation, Reynolds and Mach numbers. Similar phenomena are present in the test section with partially opened walls when there is no auxiliary suction of the air in the test section chamber.

Experimental data analysis of the necessary air suction from the wind tunnel test section

Experimental data from AEDC (Fig.1) show the blockage of the wind tunnel for $M = 0.77$. These measurements were obtained for the case of test section with parallel perforated walls with segmented type of perforation and with the ratio of the opened surfaces of 22,5 (%). During these measurements there was no auxiliary suction of air from the test section of the wind tunnel.

As can be seen from Fig.1, it is necessary to remove 3.6 wt.% of the air flow from the test section, and for $M = 1.2$ even 5.1 wt. % in order to archive sonic velocities in the previously described configuration. Comparing these values with the value of 3(wt.%), amount of air which is necessary to remove from the air flow in case of isentropic flow (theoretical value), it can be concluded that the difference in air flow reduction between real/experimental and theoretical value originates from the fact that auxiliary suction is removing air mostly from the boundary layer, which has significantly lower mass density when compared to isentropic flow.

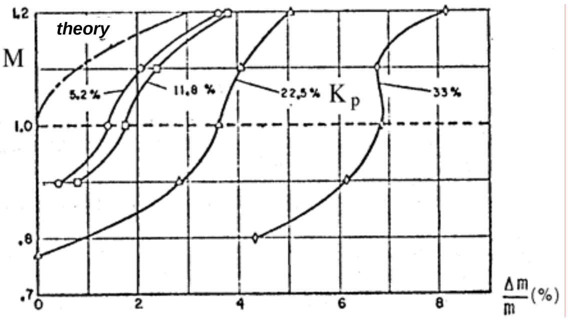


Figure 1. Minimal necessary mass reduction of the air flow as a function of M number, for different perforated walls (length of the test section was L=3.1 H, perforation diameter and wall thickness 1.6 mm, and height of the test section was H=305 mm) [1]

For the case when segmented perforation is not used, higher irregularity in the air flow quality can be compen-

---

[1] Partizanska 41, 11137 Belgrade

sated by significantly higher reduction in air flow from the test section, as it is shown in Fig.2.

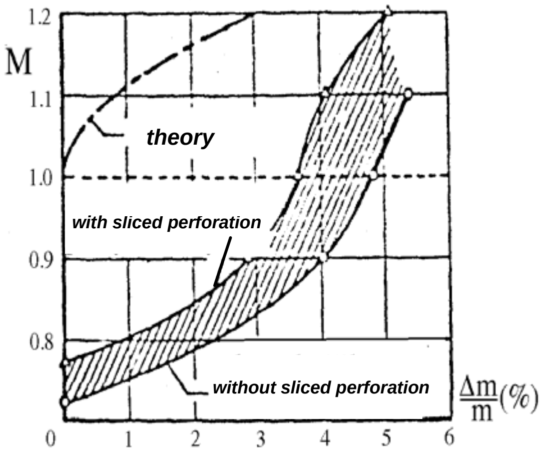
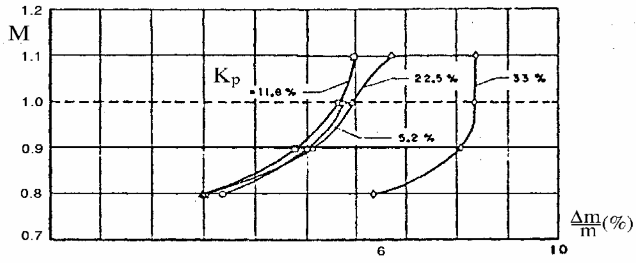


Figure 2. Minimal necessary mass reduction of the air flow as a function of M number, for perforated walls with and without sliced perforated section (for K_p=22.5 %) [1]

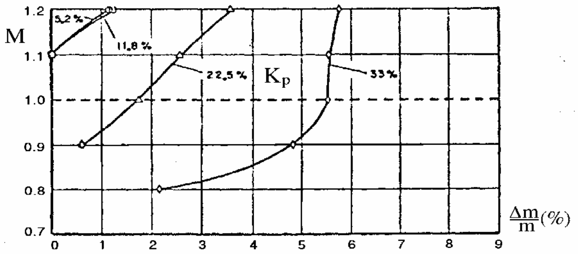
The difference in the air flow from the test section can be correlated with the local alternating in/out flow of the air to/from the test section, which depends on the adjustable pressure difference between the test section and the chamber of the wind tunnel. This alternating air flow leads to higher loses, which has to be compensated by increasing the amount of the air flow moved to the test section chamber.

From Fig.1 it is clear how big a role dimension of the perforation plays on the air flow takeout from the test section. By increasing the ratio (open surface) of the test section wall(s), the amount of air flow takeout from the test section also increases.

For the wall opened 33(%), amount of the air flow takeout from the test section, necessary for the sonic velocities to be established, was 6.9(wt.%), and for $M = 1.2$ was even 8.2(wt.%). This clearly suggests that the walls with the ratio of open surfaces so big are not convenient for practical applications. Some improvements can be achieved by using slightly divergent walls, i.e. 30('), as it is shown in Fig.3.



a) upper and lower walls convergent with 30(') convergence angle



b) upper and lower walls divergent with 30(') divergence angle

Figure 3. Minimal necessary mass reduction of the air flow as a function of M number for perforated walls with different perforation types [1]

During these measurements, only upper and lower walls were convergent (Fig.3a) and divergent (Fig.3b).

The size of perforation-slit and wall thickness have large influence on the efficiency of the perforated walls, i.e. on the development of the boundary layer and on the necessary auxiliary suction of the air from the test section. This influence is shown inn Fig.4.

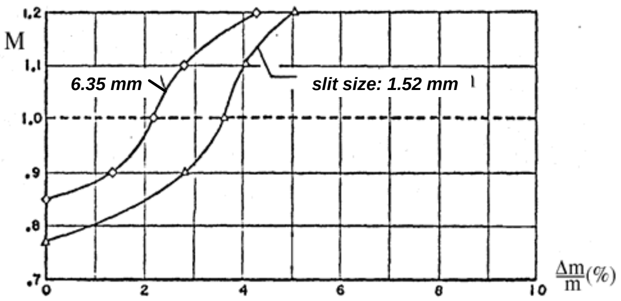


Figure 4. Minimal necessary mass reduction of the air flow as a function of M number for parallel perforated walls with the 22.5% opened surfaces and 1.6 mm thick walls, but for different perforation - slit sizes [1]

From Fig.3b it is clear that the air flow blockage is reduced, therefore the necessary air flow takeout to the chamber of the test section has also been reduced. On the other hand, using slightly convergent walls, in order to achieve uniform air flow in the test section, there is an increase in the necessary air flow takeout from the test section. The later case is shown in Fig.3a.

From Fig.4 it is clear that the mass of the air that needs to be removed from the test section decreases with increasing the slit size.

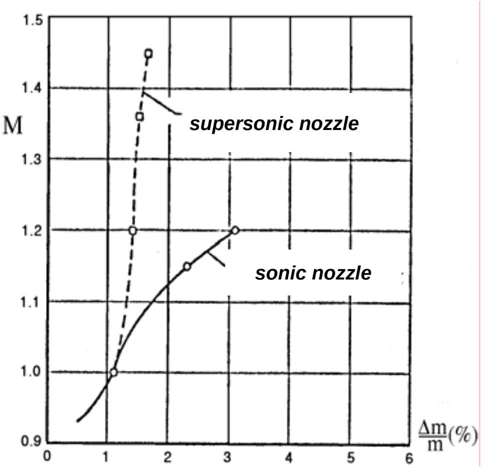


Figure 5. Minimal necessary mass reduction of the air flow as a function of M number for perforated walls (11.8% opened surfaces) with and without supersonic nozzle[1]

In case when supersonic nozzle is used for establishing the supersonic air flow, significantly lower suction of air from the test section is required. This is understandable since in this case air suction serves to compensate for the boundary layer formed along perforated walls and not to establish supersonic air flow which would be the case if supersonic nozzle were not used. Minimal value of the air that needs to be removed from the test section for perforated walls with the ratio of the opened surfaces of 11.8(%), with and without the supersonic nozzle, are shown in Fig.5, based on experiments done in AEDC and ARA laboratories.

From Fig.5 it can be seen that for compensation of the boundary layer, when supersonic nozzle is used, it is necessary to evacuate 1.1(%) air mass from the test section for $M = 1.0$, and only 1.7(%) for $M = 1.45$.

Based on previous analysis and experimental results of different aero dynamical laboratories - wind tunnels, it can be concluded that, in order to obtain high-quality air flow field in the test section of transonic wind tunnel, correct determination of the perforated walls geometry is of utmost importance. Correct geometry of perforated walls in combination with suitable auxiliary air suction from the test section to the chamber of the test section will reduce interference from the test section walls to the minimum or, in other words, will provide the flow conditions in proximity of the walls very similar to those of the air flow in free flight conditions for the given aircraft model.

Large amount of experimental data from large number of aero dynamical laboratories around the world are used in the initial phase for determining the optimal geometry of the perforated walls (for transonic wind tunnels). Final verification of the proposed geometry is realized with test-models. Based on these tests and with suitable mathematical modeling it is possible to define wind tunnel corrections of the test section walls, which serves as the foundation for correction of the measured parameters in transonic wind tunnels.

On one hand, perforated walls are eliminating the blockage effect and reflection of striking waves, but on the other, it cannot in full eliminate their one interference. This uneliminated self-interference can be compensated by applying the calculated corrections for the transonic wind tunnels.

Conclusion

Based on previous analysis and shown experimental results of different aero dynamical laboratories it can be conclude that, in order to achieve high-quality flow field in the test section of the transonic wind tunnel, geometry of the perforated walls has to be appropriately defined. This, in combination with suitable auxiliary air suction from the test section to the chamber of the test section will reduce interference from the test section walls to minimum and provide the flow conditions in proximity of the walls very similar to those of the air flow in free flight conditions for the given aircraft model.

References

[1] GOETHERT,B.: *Transonic Wind Tunnel Testing*, AGARDDograph 49, Pergamon Press, New York, 1961.

[2] SHAPIRO,A.: *The Dinamics and Thermodyamics of Compressible Fluid Flow*, Volume II, Ronald Press Company, New York, 1954.

[3] POPE,A., GOIN,K.L.: *High Speed Wind Tunnel Testing*, John Wiley&Sons, Inc., New York, 1965.

Received: 15.10.2003.

Analiza potrebne količine odsisavanja vazduha iz radnog dela aerotunela u transoničnoj oblasti brzina

U zatvorenom radnom delu aerotunela sa paralelnim zidovima efektivna površina poprečnog preseka se postepeno smanjuje u pravcu strujanja vazduha zbog kontinualnog narastanja debljine graničnog sloja duž zidova radnog dela aerotunela. Kao posledica ove pojave, sonična brzina će biti uspostavljena na kraju radnog dela iako je brzina na početku radnog dela još znatno ispod M=1. Da bi se postigla sonična brzina u praznom radnom delu zatvorenih zidova, potrebno je da zidovi budu divergentni, što zavisi od hrapavosti zidova, Reynolds-ovog broja i Mach-ovog broja. Slični fenomeni su prisutni i u radnom delu sa parcijalno otvorenim zidovima, kada se ne koristi pomoćno odsisavanje vazduha u komoru radnog dela.

Za dobijanje uniformne struje vazduha u random delu aerotunela sa perforiranim zidovima potrebno je vršiti pomoćno odsisavanje vazduha iz radnog dela u komoru radnog dela.

Ključne reči: **aerodinamički tunel, aerodinamičko ispitivanje, transsonično strujanje.**

Анализ необходимого количества отбора и высосывания воздуха из рабочей части аэродинамической трубы в околозвуковой области скоростей

В закрытой рабочей части аэродинамической трубы со параллельными стенами эффективная поверхность поперечного разреза постепенно уменьшивается в направлении потока воздуха из-за постоянного нарастания толщины пограничного слоя вдоль стен рабочей части аэродинамической трубы. В роли следствия этого явления, звуковая скорость будет установлена в конце рабочей части, не смотря на то, что скорость на начале рабочей части еще значительно меньше M = 1. Чтобы добится звуковой скорости в пустой рабочей части закрытых стен, нужно чтобы стены были дивергентными, а это зависит от шероховатости стен, числа Рейнольдса и числа Маха. Подобные явления присущи и в рабочей части со частично открытыми стенами, когда не пользуется вспомогательный отбор воздуха в камеру рабочей части. Для получения единообразного потока воздуха в рабочей части аэродинамической трубы со перфорированными стенами необходимо совершить вспомогательный отбор воздуха из рабочей части в камеру рабочей части.

Ключевые слова: аэродинамическая труба, аэродинамическое исследование, околозвуковой поток.

Analyse de la quantité nécessaire de la succion d’air de la chambre d’expérience de soufflerie dans le domaine transsonique des vitesses

Dans la chambre d’expérience fermée de la soufflerie aux parois parallèles la surface effective de la section transversale diminue graduellement dans le sens du courant d’air à cause de la croissance continue de couche limite le long des parois de la chambre d’expérience de soufflerie. En conséquence de ce phénomène, la vitesse sonique sera réta- blie à la fin de chambre d’expérience bien que la vitesse au début de celle-là soit encore sensiblement inférieure à M=1. Pour obtenir la vitesse sonique dans la chambre d’expérience vide au parois fermés, il est nécessaire que les parois soient divergents, ce qui dépend de la rudesse des parois, des nombres de Reynolds et Mach. Des phénomènes similaires existent aussi dans la chambre d’expérience aux parois partiellement ouverts quand on n’utilise pas la succion auxiliaire d’air. Pour obtenir les courants d’air uniformes dans la chambre d’expérience de la soufflerie aux parois perforés, il est néces-saire d’effectuer la succion auxiliaire d’air dans la chambre d’expérience.

Mots clés: **soufflerie aérodynamique, essai aérodynamique, courant transsonique.**