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EXPERIMENTAL STUDY ON THE PRESENCE OF OPEN CAVITY EFFECTS ON INTERNAL FLOW AND CONVECTION HEAT TRANSFER CHARACTERISTICS

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ABSTRACT

An experimental study is conducted to investigate the effect of open cavity on the pattern of fully developed internal flow and convection heat transfer. In this experimental work the velocity profile, temperature distribution, heat transfer coefficient and Nusselt number were determined at various Reynolds numbers ($1.9*10^4 \le Re \le 2.7*10^4$) for smooth surface as well as for flow over open cavity (with and without excitation). The results showed that the presence of the cavity led to change the downstream velocity profile and the dissimilarity of downstream skin friction coefficient between the upper and lower surfaces around (64 %) at distance to the length cavity (x/L= + 20.5). As a result the heat transfer coefficient and Nu increased downstream of the cavity especially at (x/L= + 20.5) around (30 %). The effect of cavity excitation with different sound levels (100,107.5 and 115) dB and frequencies (25,50 and 100) Hz was small compared with the cavity itself.

الخلاصة

يتناول البحث دراسة عملية لتاثير الفجوة المفتوحة على طبيعة الجريان و انتقال الحرارةبالحمل جري ان كامل ال تطور .تم
ايجاد منحنى السرعة, توزيع درجات الحرارة, معامل انتقال الحرارة اضافة الى حساب رقم نسلت لمواقع مختلفة على سطح
املس و سطح يتضمن فجوة مفتوحة (بعدم وجود اثارة و بوجود اثارة) عند اعداد رينولدز مختلفة $(1.9*10^4 \le Re \le$
$2.7*10^4)$. اشارت النتائج الى ان وجود الفجوة يؤدي الى تغير منحنى توزيع السرعة خلف الفجوة اضافة الى عدم التماثل لقيم
معامل الاحتكاك الموضعي للسطح العلوي و السفلي بحدود (64 %) عند ساف ة ال ى طول ف جوةم(x/L= +20.5) .
نتيجة لذلك فان كل من معامل انتقال الحرارة الموضعي و عدد ن سلت ازداد بصورة ملحوظة و خصوصاً عند (
x/L= +20.5) دودحب (30 %) . كما اشارت الدراسة الى ان تأثير الاثارة للفجوة ضغط (100,107.5&115dB)
ب م س توي ات (25,50&100 Hz) ت و ت رددا على النتائج ال م س تح صلة يكون صغير مقارنةً بتأثير الفجوة نفسها.

INTROUDACTION

The problem deals with the internal flows encountered in many industrial processes, where a fluid has to transport in a piping system. All the valves or other elements may great flush mounted cavity. Flow interaction with a structure produces vortices with shed at a prescribed frequency. If the shedding frequency coincides with the resonance frequency of an adjoining elastic structure or acoustic fluid volume within the cavity, the resulting oscillation can reinforce the vortices creating a feed back mechanism responsible for producing high energy at resonance. This phenomenon is called lock-in and at low Mach number can result in a strong narrow band sound source. Lock-in is often undesirable and can promote rapid fatigue failure [3]. The flow over open cavity can be explained according to [4] which showed that at the up-stream edge of the cavity a boundary layer separates. The resulting shear layer develops based upon its initial conditions and the instability characteristics of the mean shear-layer profile. The shear layer spans the length of the cavity and ultimately reattaches near the trialing edge of the cavity in an open cavity flow. The reattachment region acts as the primary acoustic source. The incident acoustic waves force the shear layer, setting the initial amplitude and phase of the instability waves through a receptivity process. The effect of sound on a free convection heat transfer from a vertical flat plate had been studied in [2] and showed that, intense acoustic fields result in significant increase in the rate of free convection heat transfer and heat transfer coefficient with increasing intensity of a caustic field. The cavity problem has long been an attractive problem for researchers due to the rich nature of the flow physics and it relevance to practical applications [8]. Even though many researches studied the flow and heat transfer a long smooth surface in the rectangular duct [5] and the flow over open cavity and it attempted to control the flow over it using open-loop and closed-loop control [1, 4, 6, 9]. These studies did not deal with the effect of these methods and cavity effect on the flow pattern and at the same time on the heat transfer characteristics.

The goal of this work is to investigate experimentally the effect of open cavity (with and without excitation) on the internal flow and heat transfer characteristics.

EXPERIMENTAL FACILITY

The experiments were performed in an open rectangular duct, using air as the working fluid. The duct has cross section (1.006*.03 m) and is over 10.35 m long. At the outlet section of the duct two centrifugal fans were fixed. The upper and lower walls of the duct made of plywood of (15 mm) thickness. The lower wall was instrumented with embedded thermocouples to measure the local temperature of the surface. The thermocouples junction was embedded with epoxy resin in the holes drilled upward from the lower wall. The lower surface was electrically heated by using strips foil of nichrome to serve as a source of heat. The heating element consists of strips of (2 cm) width. Foil strips were placed adjacent to each other with spacing of around (1 mm) between them and heated by alternating current to serve as constant heat flux. The lower wall was insulated to ensure that the input heat was mainly dissipated to the air. The side walls of the duct made of Perspex pieces. The first section of the duct with length (3.625 m) was used as working section and practically all the measurements were recorded. A cavity with length (6 mm), depth (50 mm) and width (750 mm) was formed on the lower surface of the duct at a distance (1.2 m) from the working section. Loudspeaker was fixed at the lower end of the cavity.

A 20 mm hole was provided at one wall of the cavity box for the insertion of the microphone. Fig (1) shows the working section and measurement locations. The excitation of the cavity with different frequencies and amplitudes was generated from signal generator and transmitted to the cavity through loudspeaker. The output from microphone was fed to a sound level meter which its reading is in dB. For static and total pressure measurements, holes were drilled due to (British-Standard) at the upper wall of the duct. For static pressure measurements the tapings were connected to micro manometer with (1%) accuracy and a range (1-10 mm H_2O). Measurements of local velocity within the boundary layer were made using a Pitot probe (with outer diameter 1.5 mm) and its working end chamfered to obtain measurement at 0.25 mm from the attachment wall. The tube was screwed to a special probe carrier in which Dial gauge was connected. The dial gauge gave 30 mm reading range with accuracy of 0.01 mm.

DATA ANALYSIS

Surface temperatures were measured with thermocouples embedded along the foils. The net convective heat from the face of foils was obtained by subtracting losses from insulated surfaces and radiation losses from metered electric energy input to the foil [5], as follow,

$$Q_{con} = Q_{gen} - Q_{loss} \tag{1}$$

$$Q_{gen} = I^2 \times R \tag{2}$$

$$R = 14.475 + 0.061 \times (T - T_o) \tag{3}$$

$$Q_{loss} = -0.41 + 0.0784 \times \Delta T - 4.863 \times 10^{-4} \times \Delta T^2 \tag{4}$$

Where,

$\Delta T = T - T_o$

$$h = \frac{Q_{con}}{A \times (T - T_{bn})} \tag{5}$$

$$Nu = \frac{h \times D}{k} \tag{6}$$

RESULTS AND DISSCSION

The experiments had been tried with three cases,

1- smooth surface (cavity covered with tape)
2- cavity without excitation
3- cavity with excitation at different frequencies and levels.

Velocity Profile

Velocity was measured using a total head tube and wall static pressure tapings. The velocity measurements were carried out upstream of the cavity at distance to the cavity length (x/L= -16.25) and downstream of the cavity (x/L= +20.5, x/L= +78.9, x/L= +137.9) as shown in figure (2). The velocity profiles were found to be identical in the flow direction. The existence of cavity led to change the velocity profile especially at (x/L= +20.5) as shown in figure (3) due to a periodic vortex organization which periodical impacts the downstream edge of the cavity and caused the change of velocity profile [4]. The dissimilarity of velocity profile down stream the cavity diminished at (x/L= +137.9). The effect of cavity excitation with 25 Hz and 100 dB on velocity profile have been insensitive compared without excitation, except of a certain variation in the inner region at (x/L= +20.5) as shown in figure (4). Figure (5) shows the effect of changing the pressure level of excitation from 100-115 dB at the same frequency at x/L= +20.5. From the figure it is clear that the highest value of pressure level has the greater effect.

Skin Friction Coefficient

The values of C_f were measured for the above three cases using Preston tube (Di/Do=0.6) [7]. The measurement for upper and lower surfaces gave nearly the same values for smooth surface, maximum difference (9%) as shown in figure (6). The existence of cavity caused a large difference between these values particularly at x/L= 20.5 (64%) as shown in figure (7). The difference between these values related to the variation of velocity profile for two surfaces. The comparison between C_f for smooth surface and that for cavity is shown in figure (8). The excitation of cavity did not cause clear effect on the values of skin friction coefficient in comparison with that for cavity without excitation except at x/L= +20.5 as shown in figure (9, 10).

Heat Transfer Coefficient And Nusselt Number

Figure (11) shows the heat transfer coefficient (h) along the test section for smooth surface at different values of Reynolds number. From the figure it is clear that (h) is nearly constant along smooth surface. The existence of cavity led to a sharp increase in heat transfer coefficient at x/L= +20.5, which disappeared along the remainder distance as shown in figure (12). The excitation of cavity with different values of frequency and amplitude maintained the same trend of heat transfer coefficient as that for cavity without excitation although the excitation caused a certain increase in (h) at x/L= +20.5 as shown in figures (13, 14). From eq. (6) Nu number was calculated for smooth, cavity and cavity with excitation, and from figures (15-18) the same results and trend of variation for Nu were obtained as that for h.

The weak effect of excitation of the cavity on the above results may be related to the amplitudes and frequencies lying around the values of that for cavity without excitation as shown in figure (19). All the above results of smooth surface in the fully developed region were compared with [5] and gave good agreement as shown in Table. 1.

CONCLUSIONS

- The greater effect of cavity confined to x/L= +20.5 downstream of the cavity.
- Vortex organization within the cavity led to alter the velocity profile and caused the dissimilarity of skin friction coefficient for upper and lower surfaces around (64%) at x/L = +20.5 as well as increased heat transfer coefficient (h) and Nusselt number around (30 %) at x/L= +20.5.
- The excitation of cavity with different amplitudes and frequencies had small effect on the results compared with self cavity and almost confined to x/L= +20.5.
- The variation of Re number ($1.9*10^4 \leq Re \leq 2.7*10^4$) had not significant effect of the obtained results.

REFERENCES

- Hamed A., Das K., and Basu D. (2004), Numerical simulations of fluidic control for transonic cavity flows. 42nd AIAA Aerospace Sciences Meeting & Exhibit. pp. 1-8.

- June R.R., and Baker M. J. (1963), The effect of sound on free convection heat transfer from a vertical plate. Journal of heat transfer. pp.279.

- Klai-Fook Cody, Hambric S. and Pollack M. (2005). Challenges of investigating fluid-elastic lock- in of a shallow cavity and a cantilevered beam at low Mach numbers. LM-05K127. pp. 1-9.

- Louis Cattafesta, David Williams, Clancy Rowley and Farruk Alvi. (2003). Review of active control of flow- induced cavity resonance. 33rd AIAA Fluid dynamics conference. pp.1-20.

- Lwaa N. (1992). Experimental study to flow and heat transfer in the rectangular duct centered with diffuser section at different angles. M.Sc. Thesis, University of Technology, Mech. Dept.

- Pascal Hemon, Xavier Amandolese, Francoise Santi and Jan Wojciechowski (2002). Study the acoustic oscillation of flow over cavities. Part 2. Sound Reduction. ASME International Engineering Congress & Exposition. pp. 1-7.

- Patel V.C. (1965). Calibration of Preston tube and limitation on its use pressure gradients. J. Fluid Mec., vol. 23. pp. 185-208.

- Samimy M., Debiasi M. and Caraballo E. (2003). Development of closed-loop control for cavity flows. 33rd AIAA Fluid Dynamics Conference and Exhibit. pp. 1-17.

- Xavier Amandolese, Pascal Hemon and Clotide Regardin. (2002). Study the acoustic oscillation of flow over cavities. Part 1.Internal Fl;ows. ASME International Engineering Congress & Exposition. pp. 1-9.

NOTATION

A	foil surface area (m^2)
Cf	skin friction coefficient
D	cavity depth, effective diameter (mm,m)
dB	decibel
F	frequency (Hz)
h	heat transfer coefficient ($W/m^2.\,^oC$)
I	electric current flow rate (amp)
k	thermal conductivity ($W/m.^oC$)
L	cavity length (mm)
Nu	Nusselt number
Q	heat transfer rate (W)
R	electric resistance (Ω)
Re	Reynolds number ($U_c.D/\nu$)
T	foil temperature (^oC)
U	stream wise velocity component (m/s)
w	cavity width (mm)
x	stream wise coordinate
y	vertical coordinate

SUBSCRIPTS

b	baulk
c	center
con	convective
gen	generated
loss	losses
n	number of foil
o	ambient
bn	baulk at specified foil

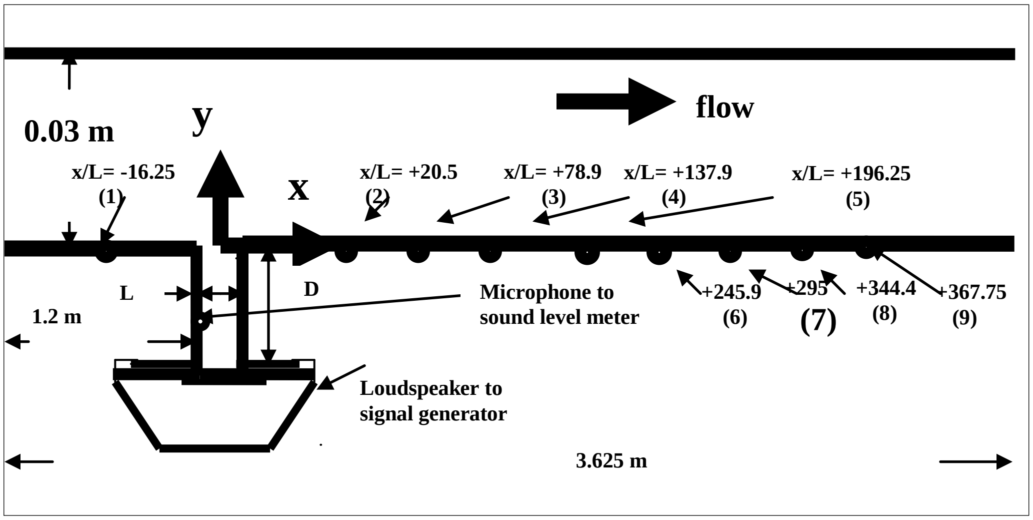


Fig.1. working section and measurement locations

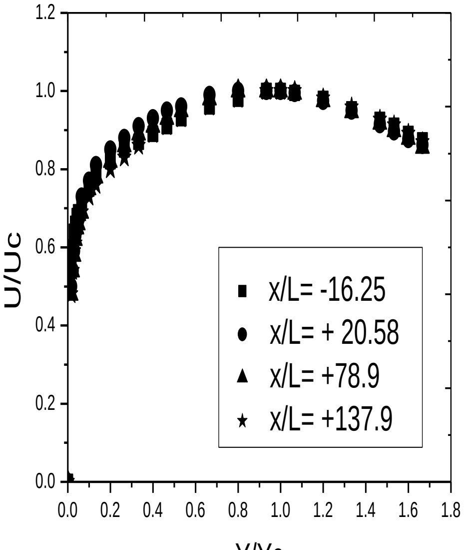


Fig.2. velocity profile for smooth surface at Re= $2.3*10^4$.

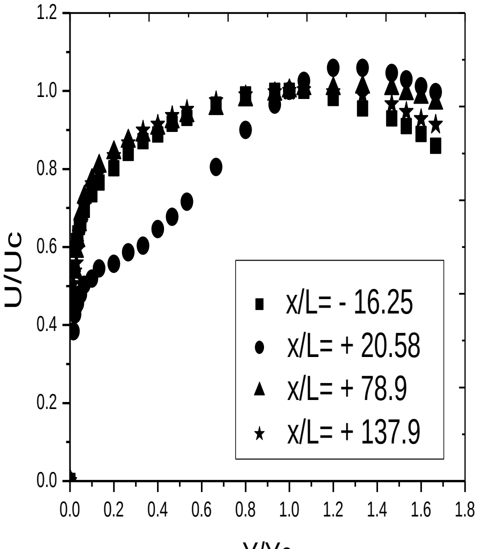


Fig.3. velocity profile for cavity without excitation at Re= $2.3*10^4$.

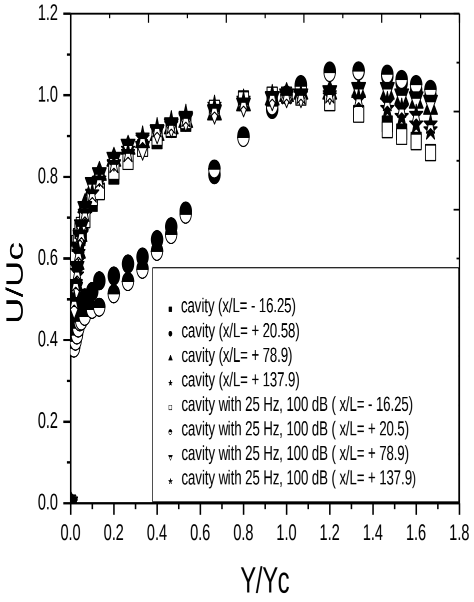


Fig.4. velocity profile for cavity with excitation and without excitation at Re= $2.3*10^4$

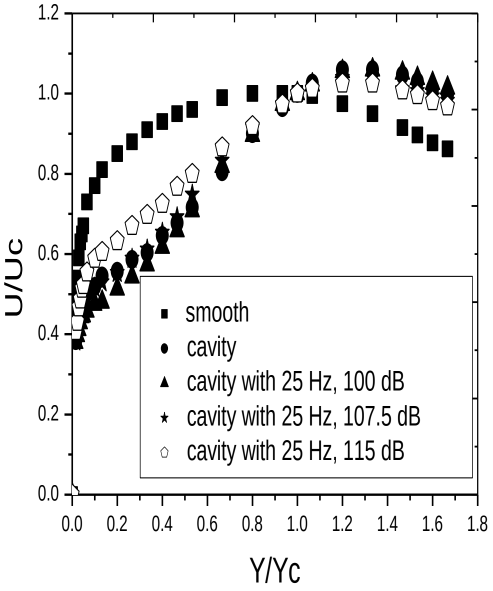


Fig.5. velocity profile for smooth, cavity with excitation and without excitation at x/L= 20.5 and Re= $2.3*10^4$.

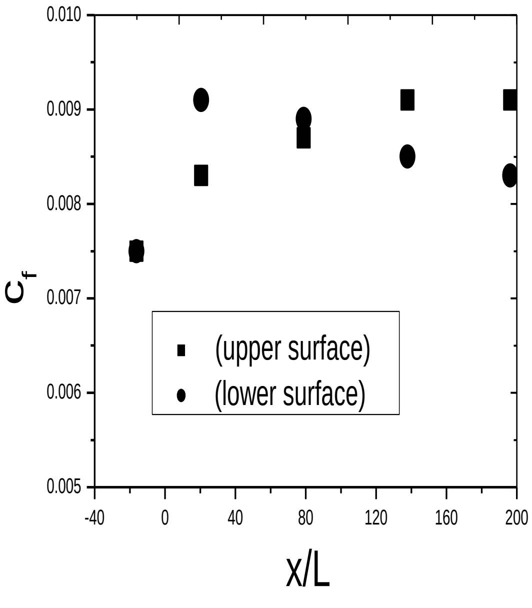


Fig.6. local skin friction coefficient for smooth surface at Re= $2.3*10^4$.

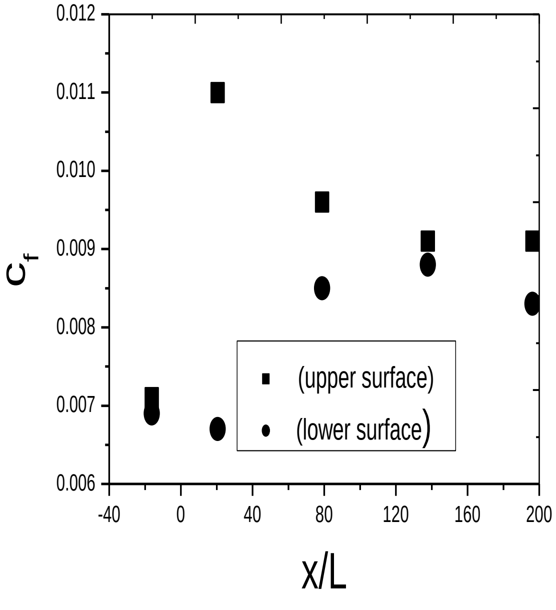
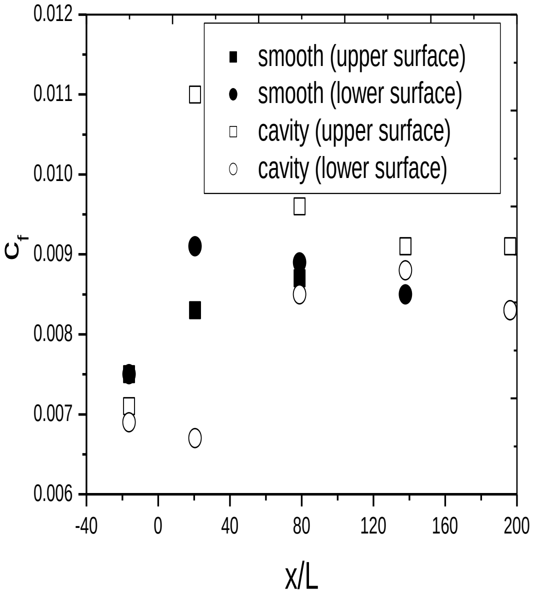


Fig.7. local skin coefficient for cavity without excitation at Re= $2.3*10^4$.



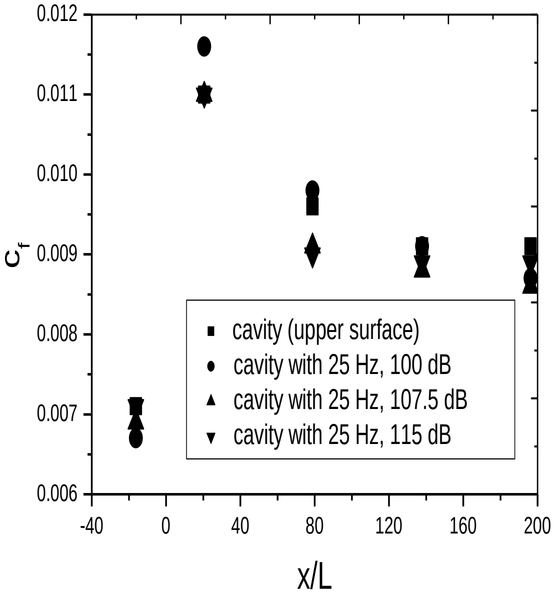
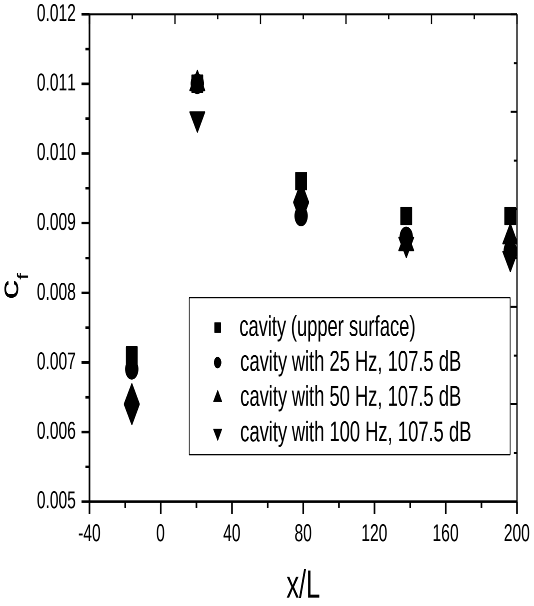


Fig.8. local skin friction coefficient for smooth and cavity without excitation at Re= 2.3*10^4.

Fig.9. local skin coefficient for cavity with excitation and without excitation with different levels at Re= 2.3*10^4.



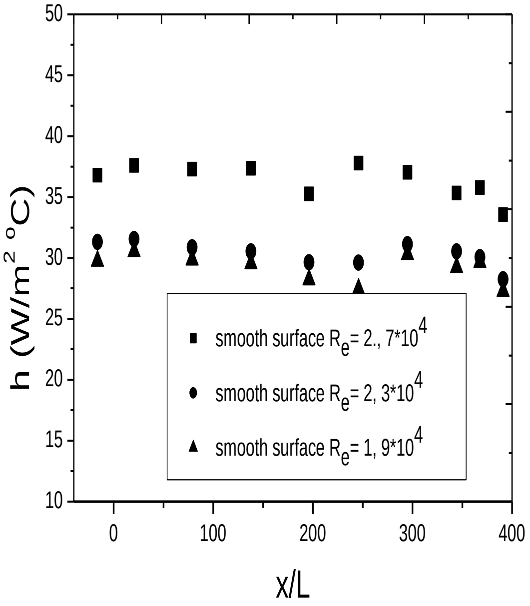


Fig.10. local skin friction coefficient for cavity with excitation and without excitation with different frequencies at Re= 2.3*10^4.

Fig.11. variation of local heat transfer coefficient along smooth surface at different Re numbers

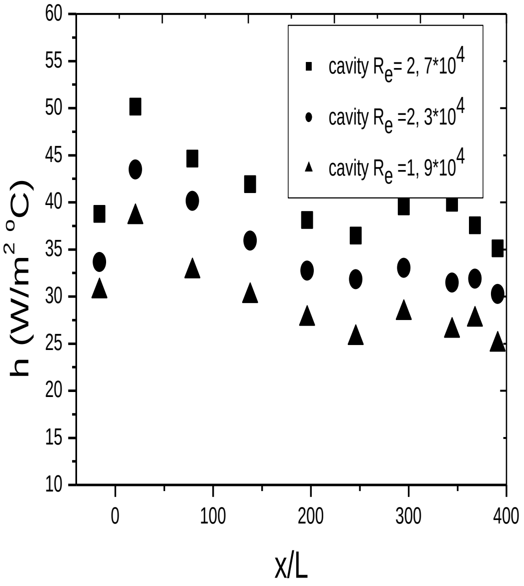


Fig.12. variation of local heat transfer coefficient along cavity without excitation.

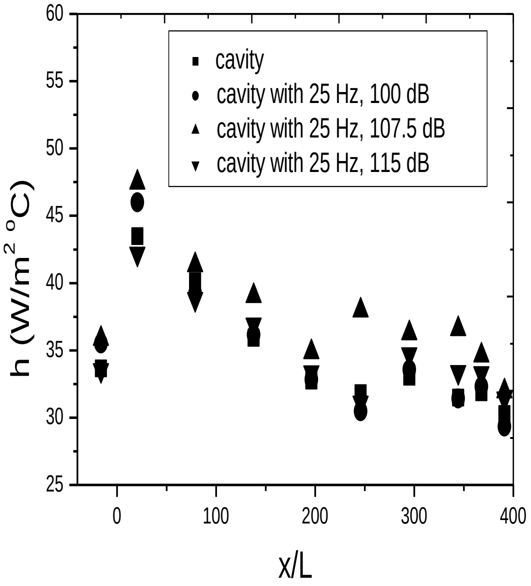


Fig.13. influence of excitation the cavity with different levels on the local heat transfer coefficient at Re= $2.3*10^4$.

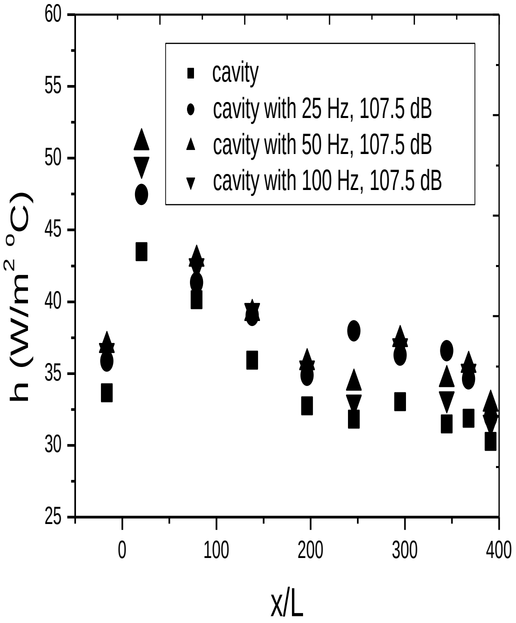


Fig.14.influnce of excitation the cavity with different frequencies on the local heat transfer coefficient at Re= $2.3*10^4$.

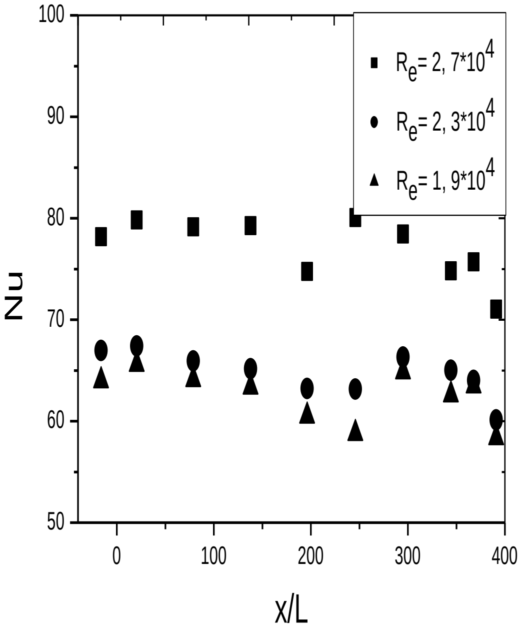


Fig.15. variation of local Nu along smooth surface at different Re numbers.

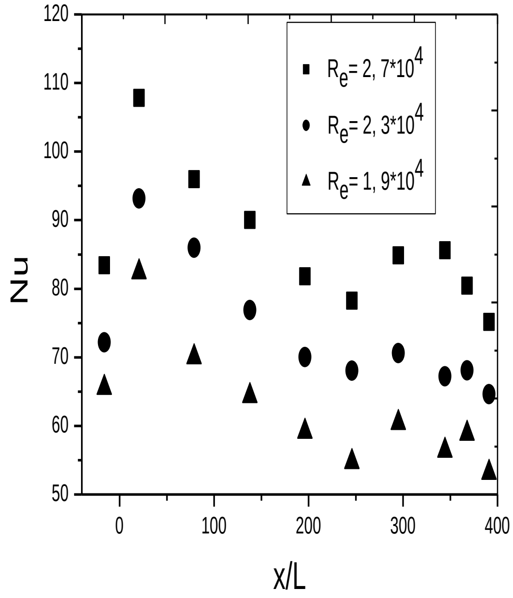


Fig.16. variation of Nu along cavity without excitation at different Re numbers.

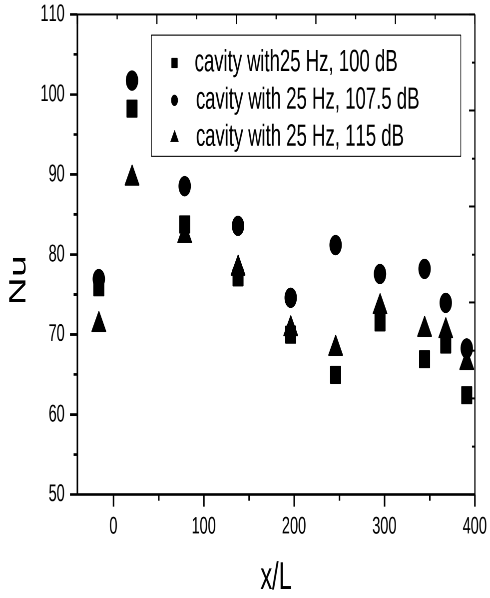


Fig.17. influence of excitation cavity with different levels on local Nu at Re= 2.3*10^4.

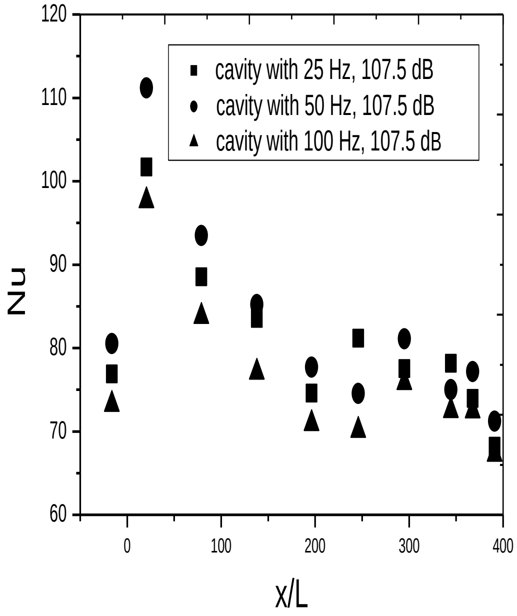


Fig.18. influence of excitation cavity with different frequencies on local Nu at Re= 2.3*10^4.

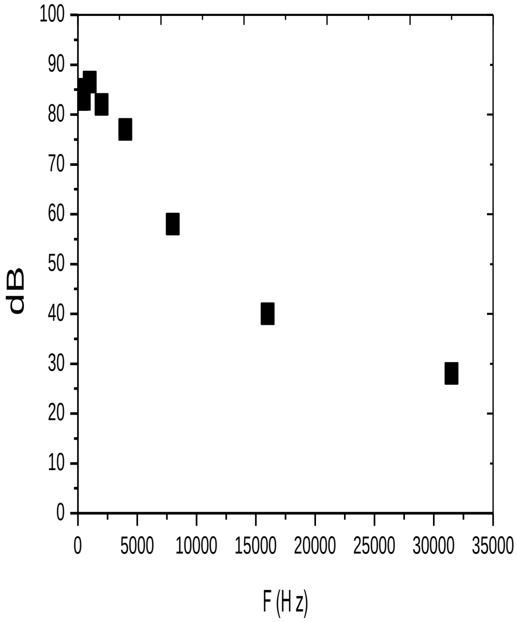


Fig.19. sound pressure level for cavity without excitation at Re= 2.3*10^4.

Table.1. Comparison between present work and reference [5]

	Re	C_f	Nu
present work	$2.3*10^4$	0.0085	65.0
	$1.9*10^4$	0.0091	62.0
refrence [5]	$4.0*10^4$	0.0064	76.0
	$3.0*10^4$	0.0070	61.0