DRAG COEFFICIENT REDUCTION IN CYLINDRICAL BODIES USING A DOWNSTREAM WAVY FIN [+]

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Abstract :

An investigation was performed to show how drag force and hence drag coefficient will be reduced when using a wavy shape fin attached to the trailing edge of a cylindrical body fitted normally in air stream of an open loop blower type wind tunnel.
Using wavy fin attached to cylinder body to offset any probable flow separation which may be occurred when using straight fins. Drag force measured by using momentum equation between upstream and downstream to the cylinder , this done by measuring differential pressure at a (10 *10) mesh of points chosen upstream and downstream . Work was done by testing the cylinder with no fin first then attaching straight fin and finally by attaching wavy fin in order to make result comparable.
Investigation was done in sub-critical flow regime with variable air speeds which creates of (Re) from ($4*10^3$ and $16*10^3$) with seven increments, and with 10 cm cylinder diameter and 10 cm straight fin width i.e. (L/d = 1) and apparent ratio of 0.5 . Results are then compared with that of no fin and with straight fin .Results show that to a certain limit of (Re) there is a considerable reduction in drag coef. compared with straight and no fin cylinder then it tends to decrease and become constant beyond that limit ,and there is a high reduction at low Reynolds number.
Keyword : Drag reduction , fin, wind tunnel , cylinder .

تخفيض معامل السحب للاجسام الاسطوانية باستخدام زعنفة موجية

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الخلاصة:

هذا البحث يظهر كيف أن قوة السحب (Fd) وبالتالي معامل السحب (Cd) ستنخفض باستخدام زعنفة على شكل موجة مثبتة عند الطرف الخلفي لجسم أسطواني مثبت بشكل عمودي على مجرى الهواء في مجرى هوائي من النوع المفتوح النافخ للهواء .
تستخدم هذه الزعنفة المثبتة على جسم الأسطوانة لغرض التخلص من أي انفصال في الجريان يمكن احتماله والذي لوحظ وجوده عند استخدام زعنفة مسطحة. في هذا البحث تم قياس قوة السحب باستخدام معادلة الزخم بين طرفي الأسطوانة وهذا يتأتى عن طريق قياس فرق الضغط في (10*10) نقطة موزعة أمام وخلف الأسطوانة.

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هذا العمل نفذ باستخدام أسطوانة بدون زعنفة أولا ثم باستخدام نفس الأسطوانة ولكن باستخدام زعنفة مستقيمة وأخير باستخدام نفس الأسطوانة ولكن مع زعنفة على شكل موجة جيبية حتى يمكن مقارنة النتائج بشكل أدق.

هذا البحث أجري عند منطقة (الجريان تحت الحرج) مع تغير في سرعة الهواء والتي تنتج رقم رينولد (0.4*10≤ Re ≤1.6*10) مع ٧ زيادات. الزعنفة المستقيمة طولها ١٠سم وزعنفة موجية طولها ١٠سم أيضا وقطر أسطوانة ١٠سم أي أن(L ⁄ D=1)ومعامل الظهور يساوي ٠،٥ .النتائج بعد ذلك قورنت مع تلك الأسطوانة الخالية من الزعانف وكذلك مع تلك التي تحتوي على زعنفة مسطحة. وجد أنه إلى حد معين من رقم رينولد هناك تغير واضح وملحوظ في معامل السحب مقارنة مع الأسطوانتين الأولى والثانية بعد ذلك التناقص يصبح ثابتا وأن هناك تخفيض كبير في معامل السحب عند رقم رينولد الواطئ .

Nomenclature

Article	Symbol	Unit
Drag coefficient	Cd	Dimensionless
Drag force	Fd	N
Air velocity	v	m/s
Air density	ρ	Kg/m^3
Kinematic viscosity	μ	Kg/m.s
Area	A	m^2
Differential pressure	ΔH	cm. H_2O

Introduction :

Drag reduction article occupy a great attention in the recent period due to the advantages of reducing power loss when air stream flows against bodies having cylindrical shape like pipes, rods, …etc. There are several techniques to minimize drag force including the attachment of straight fins , rotating cylinder, using splitters and others, no one deals with wavy attached fin the aim of this research .It was noticed that using straight fins downstream the cylinder causes formation of separation region especially for large diameter pipes .This can eliminated by using wavy fin which is established in the work. The magnitude of the pressure drag depends very much on the size of the wake , and this, in turns, depends on the position of separation. In the sub-critical flow regime , vortex shedding from a plain circular cylinder is periodic, resulting in an alternating circulation that generates pressure fluctuation. Thus, in addition to a mean drag force, plain circular cylinder are also subjected to fluctuating drag and lift components.

Reference[1] shows an unsteady vortex generation in the near wake when using attached traight plate. Reference[1] deals also with drag reduction in turbulent flow by decreasing friction factor of the surface , and the main purpose of drag reduction is to delay the onset of turbulent flow in boundary layer by using diluted solutions of polymers and this called “ Tom effect “.

Reference[2] shows the relationship between drag coefficient and (Re) for a cylindrical aerofoil, It increases with (Re) to a certain limit then it tends to decrease.

Reference[3] provide more details about drag coefficient reduction for oscillating cylinder through air stream. Reference[4] deals with drag coefficient of a rotating cylinder in air stream, which generates a fluid motion that has been the subject of research from the

point of view of numerical simulations, experiments and theoretical analysis. Two aspects have drawn attention with respect to streaming flow past a rotating circular cylinder. The first aspect is the observation that the spinning action is able to suppress the separation of the boundary layer around the cylinder as well as to avoid vortex shedding from the surface of the cylinder. it is found that there is a great reduction in which stalling was diminished.
Reference[5] deals with a straight fin attached to cylinder with different vane width to cylinder diameter ratio. It was found that there is a considerable reduction in drag with air velocity compared with that of no vane.
Reference[6] studies the drag reduction of circular cylinder conducted in the subcritical flow regime at Reynolds number in the range($4*10^{4} - 1*10^{5}$) To offset the unsteady vortex generation in the near weak, shield plates are used of length (L) ranged from(0.22d to 1.52d). The study shows that using shields in some geometry result in a 40% drag reduction to 55% if L/d=1.
Reference[7] studies drag reduction of natural laminar flow airfoil with a flexible surface deturbolator. This done to stabilize large extents of thin separated flow over aerodynamic surface through passive interaction with a streamwise varying pressure gradient boundary layer flow. In this study this effect has been used to reduce drag and increase lift of laminar flow airfoils at low Mach number with Reynolds number ranged from ($0.4*10^{4}$ to $1.6*10^{4}$). It was noticed that there is a reduction of 45% of drag and 10% increase in lift coefficient.
Reference[8] studies the control of flow-induced forces on circular cylinder using detached splitter plate numerically for laminar flow. Splitter significantly reduces drag force and lift fluctuation by controlling vortex shedding past circular cylinder.
Reference [9] studies experimentally reduction in drag force of circular cylinder by using small rod upstream, with(Re =20000). The form drag coefficient is obtained by integrating the surface pressure on the cylinder surface. It was found that there is a 29% reduction in drag force for (d/D=0.233) rod to cylinder diameter ratio.
The purpose of the present work was to test the hypotheses that drag force on a cylinder oriented normal to the air flow direction would be reduced by using longitudinal wavy fin attached downstream cylindrical body compared with that of no fin and another of straight fin.

Experimental Work :

1- Wind Tunnel :

It was an open circuit blower type with air stream velocity of 24 m/s max. have a test section of (32 cm * 25 cm.) cross section with a turbulence intensity level of about 0.25% flow velocity can be adjusted by inlet control damper. Test section have 10 side holes for pitot-tube insertion either up and downstream laterally and longitudinally mounted 10 cm. up and 20 cm. downstream of cylinder. Air pressure measured by using pitot and inclined manometer with fluid specific gravity of 0.875. Air stream through test section considered to be uniform along the section due to the use of two stage of screen mesh and honey combs, fig.(1) shows a schematic diagram of wind tunnel used.

2-Model :

It was a 32 cm length, 4 inches diameter galvanized steel cylindrical pipe fitted to the test section by certain bolts on both sides. A straight fin of 10 cm. width and wavelike plate 10 cm. width and wave amplitude (A) is 5 cm and its wave length of 8 cm. and looks like sine wave welded carefully to the cylinder body as shown in fig(2). The ratio of fins width to cylinder diameter equal unity. Apparent ratio for this model is 0.5(apparent ratio is the ratio between amplitude (A) to the cylinder diameter (D)) .

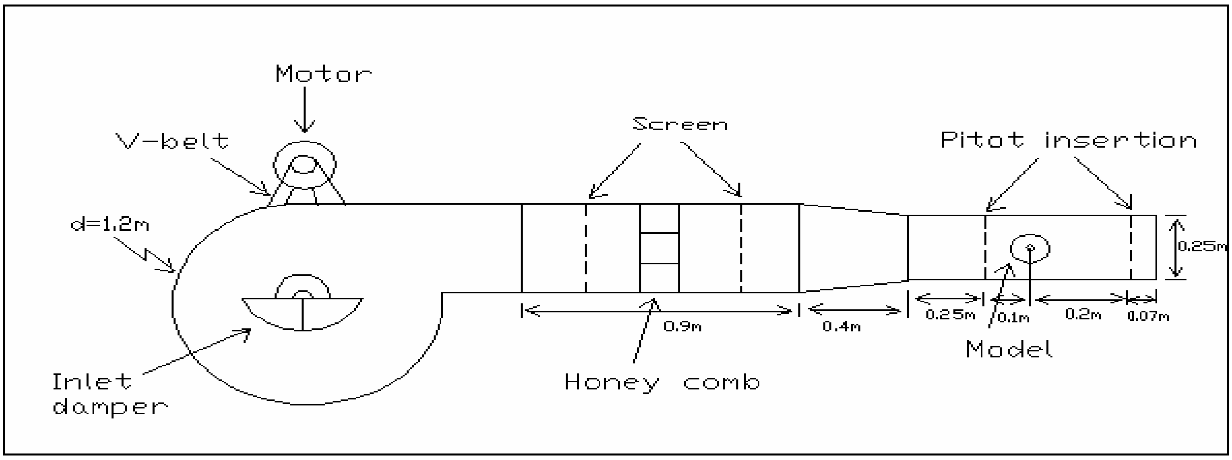

Fig.(1) Wind tunnel arrangement

3-Instrumentations :

A pitot-tube used to measured differential pressure at each point in the mesh mentioned upstream and downstream of the cylinder, and an inclined manometer used a liquid have 0.875 sp. gravity. There are ten drilled holes in the test section side wall for pitot insertion either upstream and downstream. These holes locations are

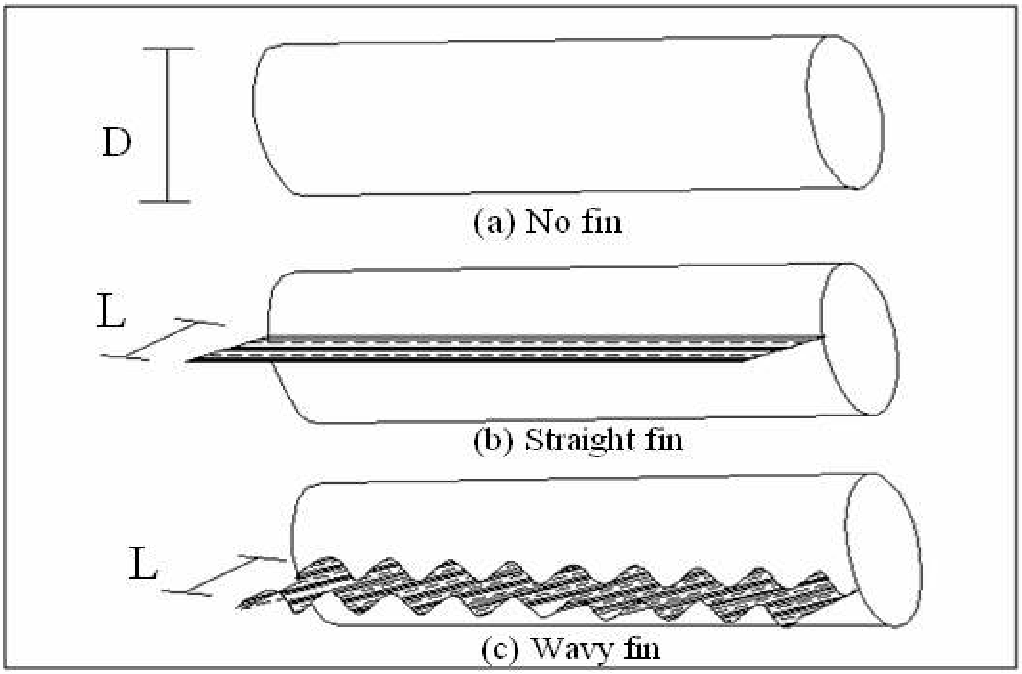

Fig.(2) Wodel arrangements

10 cm. upstream and 20 cm downstream of the cylinder, each hole can used to move Pitot horizontally 10 times, so there is 100 readings in the mesh either upstream and downstream for each run. Although test section width 32 cm, it is considered to

be 30cm width to avoid boundary layer by leaving 1 cm from both sides of test section and dimensions of meshes is (o.3cm * 0.25 cm) each. Although there is many techniques to measure drag force like strain gauge and laser beam, applying momentum equation by measuring differential pressure still good technique for good results and also due to those techniques mentioned unavailable.

Theory :

For cylinder :

$$Re = v\, d\, \rho/\mu \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (1)$$

Where: Re : Reynolds number

v	:	flow velocity	(m/s)
d	:	cylinder diameter	(m)
ρ	:	air densi	(kg/m^3)
μ	:	kinematic viscosity of air	(Kg/m.s)

$$Cd = Fd / \tfrac{1}{2}\rho v_\infty^2 A \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where : Cd : drag coefficient .

Fd	:	drag force	(N)
A	:	frontal area	(m^2)

Drag force can be measured laser technique or by using load cell unit , in this work a moment equation used to calculate drag force (Fd) :

$$Fd = \int_{Out} \tfrac{1}{2}\rho v^2 dA) - \int_{in} \tfrac{1}{2}\rho v^2 dA)$$

$$= \tfrac{1}{2}\rho A(v^2_{out} - v^2_{in}) \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$v = \sqrt{2(p2 - p1) \;/\rho air} = \sqrt{2\Delta p/\rho air}$$

$$\Delta p = \rho \text{ water } (SG \text{ manometer } g\, \Delta H)$$

Where :

SG : manometer :specific gravity of manometer fluid.
ΔH : manometer reading, and hence:

$$v = 12.76\sqrt{\Delta H} \quad (m/s) \ldots\ldots\ldots\ldots\ldots\ldots \; \ldots\ldots\ldots\ldots\ldots (4)$$

where ΔH is the differential pressure in cm. H2O
Minimum air velocity can we get from wind tunnel is 6 m/s, ρ=1.2 Kg/m^3 ,

$\mu = 1.8 * 10^{-4}$ Kg/m.s, d =0.1 m, so from eq. (1):

$$Re = 1.2 * 9.2 * 0.1 / 1.8 * 10^{-4} = 0.4 * 10^{4}$$

Maximum air velocity is 24 m/s, and hence $Re = 1.6 * 10^{4}$, so this test done for this range of Re with seven increments .

Procedure :

To identify the optimum configuration giving a minimum drag, cylinder with no fin was first fitted to the test section by two nuts both sides, the insert pitot-tube in the upper hole and read differential pressure, repeat this article ten times for this hole then move pitot-tube to the adjacent hole and repeat procedure for upstream and downstream holes mentioned, so we have 100 reading for each run. The weighted average of these reading represent the differential pressure. Then air volume increased seven times by increasing inlet damper opening and repeat the procedure above.

Secondly the same procedure was repeated to a cylinder with straight fin (L/d =1)|fitted to the test section .Third the same procedure was repeated to a cylinder with wavy fin (L/d = 1). All tests were performed at least twice to check their repeatability. It was found that the time average pressure measurements were repeatable within ± 2 % .

Results and discussion:

All readings were saved in a data-sheet, calculating air velocity, drag force and drag coefficient for each of the seven (Re) chosen. Fig. (3) shows the relationship between drag force (Cd) and (Re) for the cylinder with no fin, with straight fin and with wavy fin respectively which is done at the same laboratory air conditions of atmospheric pressure and temperature.

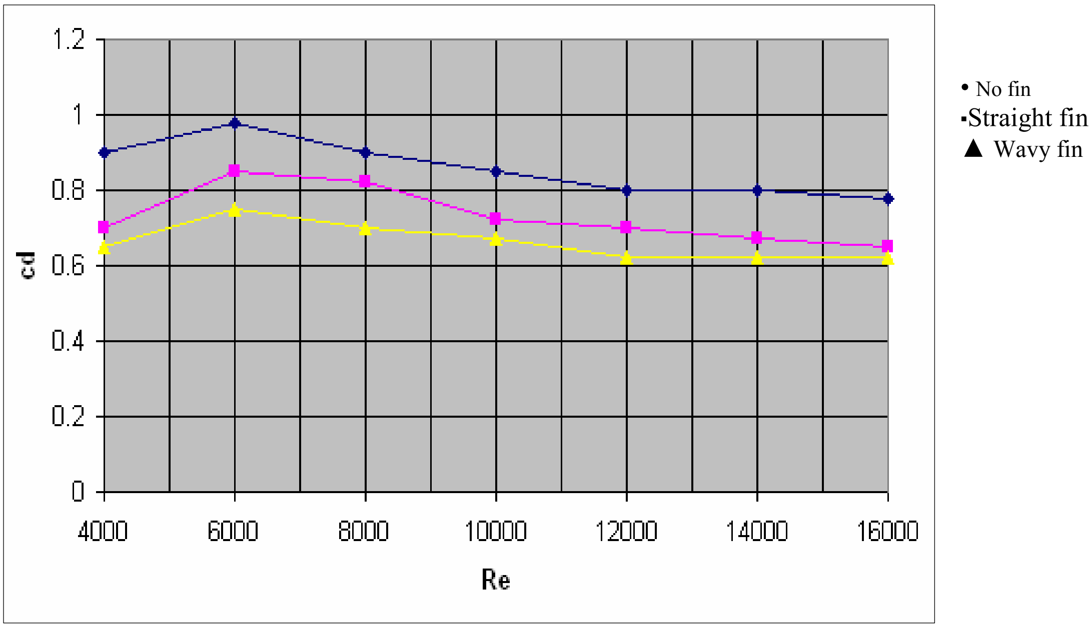

Fig (3): Drag coeff. variation with Re for the three cases

The percentage of drag coefficient reduction for the straight fin and that of wavy fin based on that of no fin was shown in Fig . (4) .

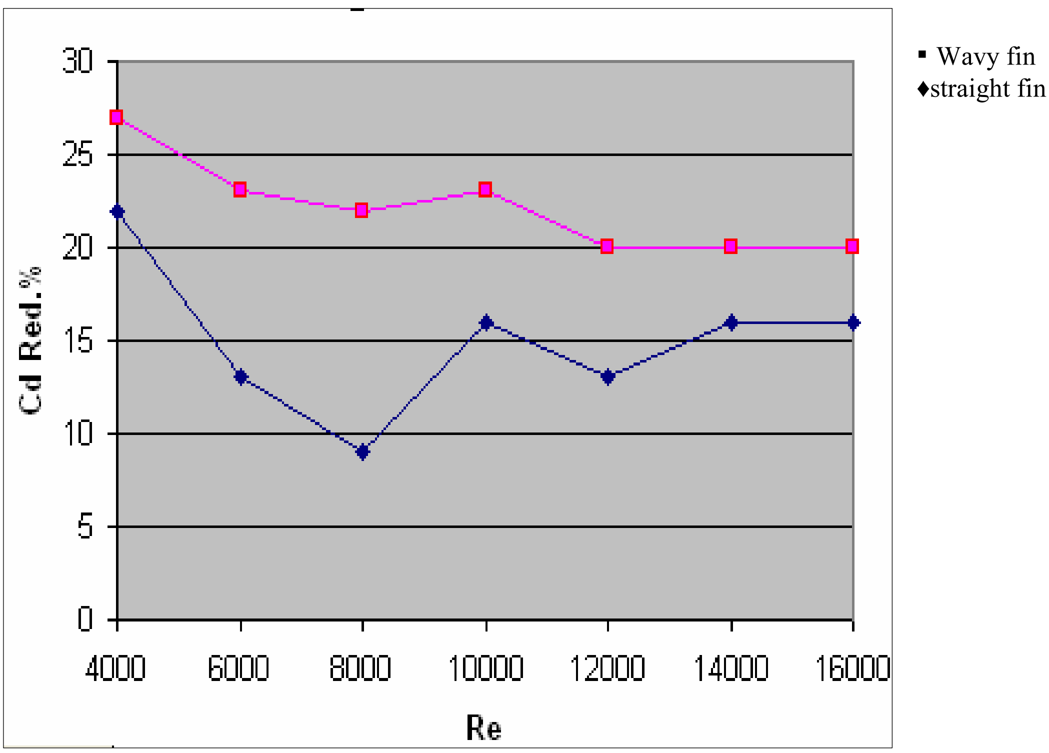

Fig. (4) drag coeff. reduction percentage with respect of no fin cylinder .

From the results obtained we can conclude the following :

1- The addition of trailing wavy fin to a smooth cylinder mounted normal to the direction of air flow can reduces drag force significantly in the range of ($4000 \leq Re \leq 16000$) .
2- The trend of (Cd – Re) relationship is the same for all cases.
3- There is an amount of reduction in drag coefficient in the range of (Re = 4000 to 10000) , after that limit , drag reduction remain constant.
4- There is a high reduction in drag force occurred using wavy fin at low Reynolds number.
5- The decrease in Cd at this work achieved due to the shifting of the separation points to the rear side of the cylinder leads to a decrease in the wake width and this decreases the negative pressure at rear, this leads of course to a reduction in drag fore. The wavy shape makes a shield zone more than flat plate.

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