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# EFFECT OF BUOYANCY ON THE FLOW AROUND TAPERED TRAPEZOIDAL PRISM

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## ABSTRACT

*The flow around bluff obstacles has been a subject of deep research for several decades and investigated both numerically and or experimentally due to its variety of applications, such as heat exchange systems, electronic cooling, flow meters and flow dividers. It has been found from literature that buoyancy effect makes flow field complex for the low range of Re and also affecting the heat transfer. This study focuses on the unconfined upward flow and heat transfer around tapered trapezoidal prisms under the effect of aiding buoyancy (Richardson number, Ri=0 and 0.5) in a vertical channel with Reynolds number (Re)=5-20 using air as a fluid.*

***Keywords: Nusselt number, Reynolds number, Richardson number and Tapered prism.***

## I. INTRODUCTION

A vast amount of literature is available on the flow and heat transfer around the bluff bodies such as circular, square and rectangular cylinders under the influence of mixed convection including aiding, opposing, and cross buoyancy. S**harma and Eswaran** [6] investigated the influence of buoyancy on the flow and heat transfer characteristics of an isolated square cylinder in the upward cross flow for Re=100 and Pr=0.7.The transition to steadiness occurred between Ri=0.125 and 0.15.**Badr** [1] investigated the problem of laminar combined convection heat transfer from a hot horizontal circular cylinder for parallel and contra flow regime for the Re of 5, 20, 40 and 60 at different Grashof number (Gr). Wakes behind circular and square cylinders have been experimentally investigated at low Re by **Singh et al. [9]**. The flow behaviour is examined from forced to mixed convection over the range of experimental conditions by varying operating parameters. Strouhal number shows a slow increase with increase in Ri. **Venugopal et al. [12]** carried out experimental investigation with several bluff body shapes such as triangular, trapezoidal, conical cylindrical and ring shapes, with water as working fluid. The effects of sampling rate, tap location and blockage effects are explored. The trapezoidal bluff body is found to be best among all the bluff bodies. **Dhiman et al.** [15] investigated the effects of cross-buoyancy and of Pr on the flow and heat transfer characterises of an isothermal square cylinder. The numerical results encompass the following range of conditions: $1 \le Re \le 30$, $0.7 \le Re \le 100$ and $0 \le Ri \le 1$ for the blockage ratio of 12.5% and Peclet number (Pe) of 3000. The main aim of this study is to investigate the buoyancy aided flow and heat transfer around tapered and expanded trapezoidal prisms at low Re, 5-20 and Ri=0-0.5for air as the working fluids

## II. PHYSICAL DESCRIPTION OF THE PROBLEM

The geometry and the relevant dimension considered for the analysis are schematically shown in Figure 1. The prism is exposed to a constant free- stream velocity in the upward direction represented as $U_\infty$ and temperature as $T_\infty$ respectively. The trapezoidal prism is maintained at a constant temperature of $T_w$ (> $T_\infty$). The upward distance (dimensionless) '$H_u/b$' from the inlet plane to the front surface of the prism and at a downward distance (dimensionless) '$H_d/b$' from the rear surface of the prism and the exit plane with total height of the computational domain is $H_T/b$. The total length (non-dimensional) of the computational domain is $L_1$ in the *x*-direction.

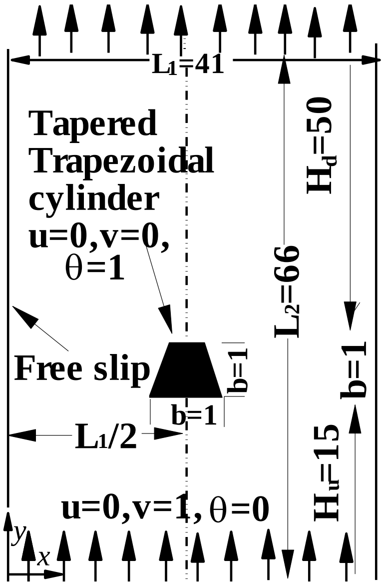


Fig 1:- Schematic of the flow around a long unconfined Tapered trapezoidal cylinder under aiding buoyancy.

The conservative dimensionless form of continuity equation (1), Navier-Stokes equations (2) and (3) and thermal energy equation (4) in two dimensions for the incompressible flow of constant viscosity fluid is given as follows:

Continuity equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

*x*- momentum equation:

$$\frac{\partial u}{\partial t}+\frac{\partial (uu)}{\partial x}+\frac{\partial (vu)}{\partial y}=\frac{\partial p}{\partial x}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \tag{2}$$

*y*- momentum equation:

$$\frac{\partial v}{\partial t}+\frac{\partial (uv)}{\partial x}+\frac{\partial (vv)}{\partial y}=-\frac{\partial p}{\partial y}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+Ri\,\theta \tag{3}$$

Energy equation:

$$\frac{\partial\theta}{\partial t}+\frac{\partial(u\theta)}{\partial x}+\frac{\partial(v\theta)}{\partial y}=\frac{1}{\mathrm{Re}\,\mathrm{Pr}}\left(\frac{\partial^2\theta}{\partial x^2}+\frac{\partial^2\theta}{\partial y}\right) \tag{4}$$

The field equations have been solved using FLUENT and the computational grid structure has been generated by commercial grid tool GAMBIT. Gauss-Siedal (GS) point-by-point iterative method in conjunction with algebric multigrid (AMG) solver is used to solve system of algebric equations.

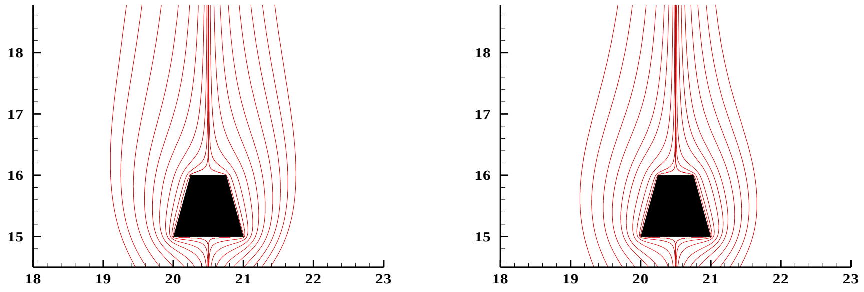
## III. RESULT AND DISCUSSION

In this work, steady flow computation have been carried out using the full domain for different values of Reynolds number (Re=5,10,20), of the Richards number 0 and 0.5 and for Prandtl number Pr=0.71 (air)

### 3.1 Flow pattern

The flow is found to be steady and symmetric for the range of conditions studied here i,e Re=5-20 and Ri=0-0.5. Figure 2 depicts the computational results in the vicinity of the tapered prism by the streamline plots at Re=5 and 20 and for Ri=0 and 0.5, Over the range of Reynolds number and at fixed Prandtl number (Pr=0.71) considered herein. The recirculation length is defined as stream-wise distance from the top surface of the cylinder to the re-attachment point along the wake centreline. As the Reynolds number is gradually increased the flow separation takes place at the trailing edge of the cylinder which results in the formation of two symmetric standing vortices behind the obstacle at different values of Re and Ri. The wake/recirculation region behind the tapered trapezoidal prism increases with the increase in Reynolds number for the constant value of Richardson number (Ri) and Prandtl number (Pr) and the wake region in the downstream side decreases with increases in Ri,

**(a) Ri=0,Re=5** **(c) Ri=0.5,Re=5**



**(b) Ri=0,Re=20** **(d) Ri=0.5,Re=20**

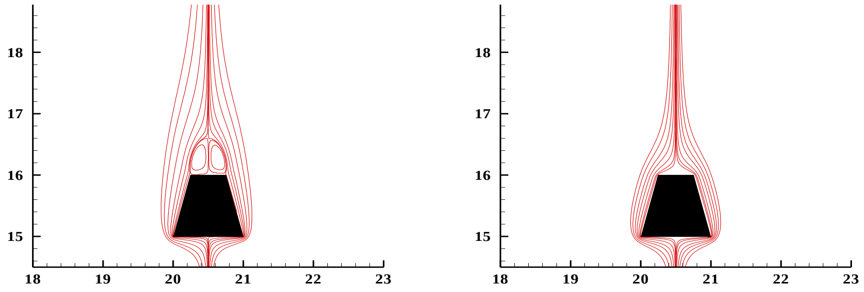


Figure2. Streamline contours around the tapered trapezoidal prism at Re=5-20 and Ri 0 and 0.5

### 3.2 Thermal patterns

The thermal patterns are observed to be more pronounced for the lower values of Re as viscous effect are more prevailing here shown in Figure 3. The temperature lines are observed to be more like that for the conduction for low values of Re and no separation of flow occurs The lateral thinning of temperature contours can be seen at higher values of Reynolds number. The crowding of isotherms is greater over those portions where the flow has not been detached. It has been observed that for fixed value of Ri, as the Reynolds number increases, the congestion of isotherms in the upstream direction increases, with the result heat transfer rate also increases. The thermal boundary layer growth starts from the bottom surface Which indicates that there is maximum heat transfer on the front surface of the cylinder followed by right and left side of the cylinder and least heat transfer from the rear side of the cylinder.

### 3. 3 Drag coefficients

The total drag is the due to the viscous (or friction) forces acting on the left and right side of the cylinder and by an unsymmetrical pressure distribution on the upstream and downstream side of the cylinder. The total drag coefficient can be partitioned as $C_D = C_{Dp} + C_{DF}$ where $C_{Dp}$ and $C_{DF}$ are the pressure and viscous drag coefficients respectively. It can be that total drag coefficient shows non-linear relationship with Re at different Ri. Individual and total drag coefficient shows an inverse relationship with Reynolds number, that is frictional drag, pressure drag and total drag decreases with Reynolds number for the same value of Ri.

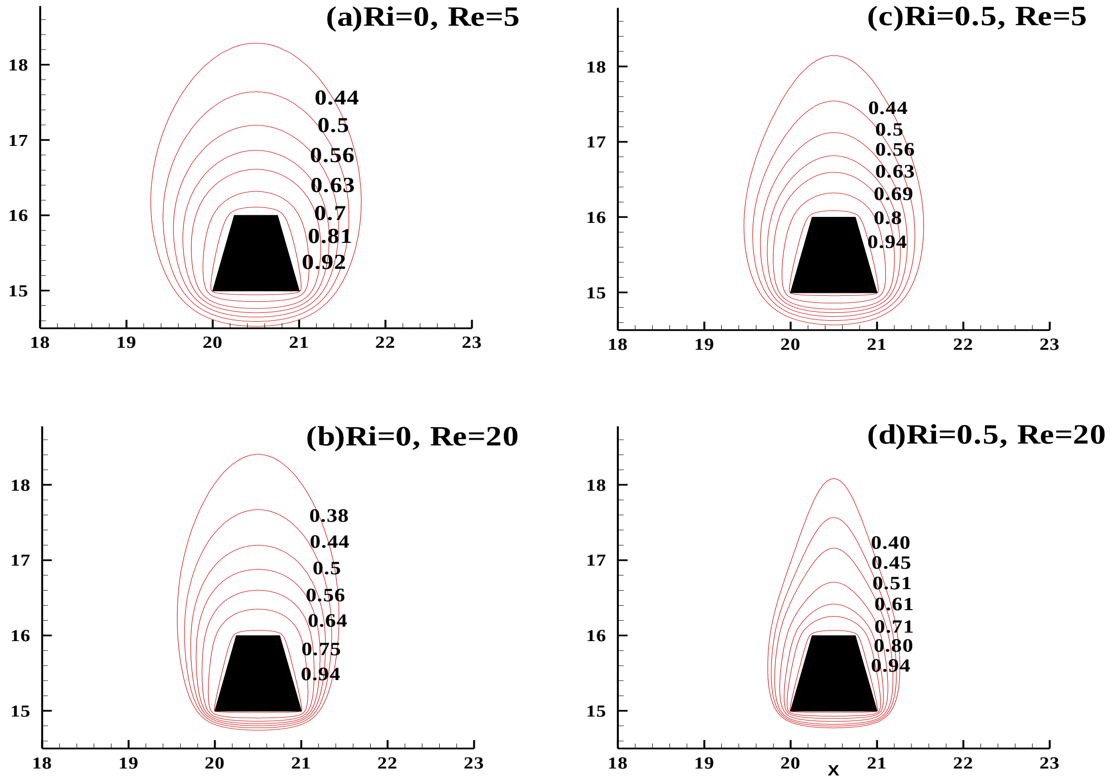


Fig.3. Isotherm patterns around the tapered trapezoidal cylinder at Re=5-20 and Ri 0-0.5

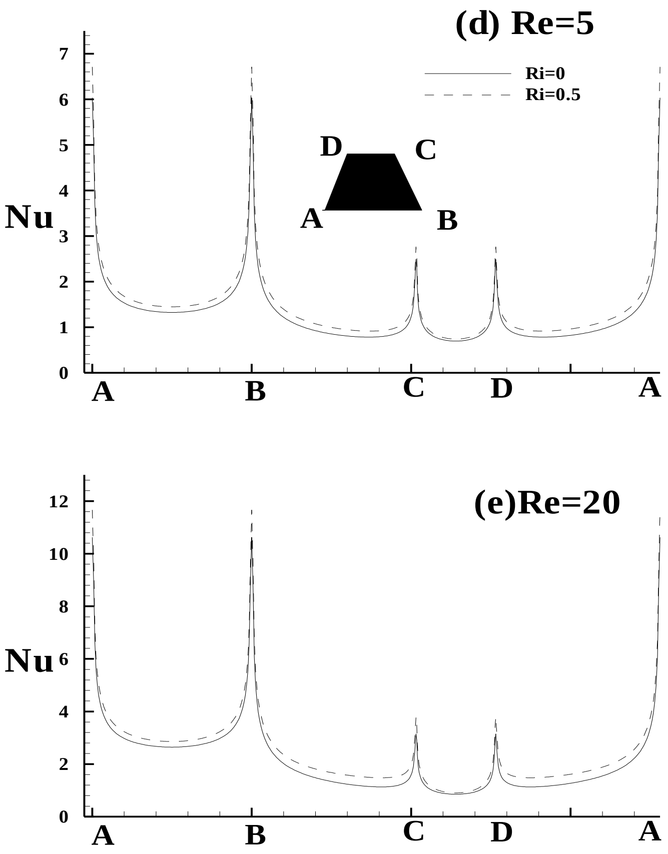


Figure 4. Variation of local Nusselt number around the four surfaces of tapered trapezoidal prism at different values of Re and Ri.

### 4.4 Nusselt number

Figure 4. depicts the variation of the local Nusselt number on the four surfaces of the 2-D tapered trapezoidal cylinder in the steady flow regime for the range of Reynolds number Re=5-20 and Ri=0-0.5 and for the working fluid as air (Pr=0.71). The values of the local Nusselt number for the forced convection (Ri=0) is found to be lower than that of mixed convection case (Ri=0.5) considered here under identical conditions. The reason for this is increase in temperature gradients with buoyancy parameter. Rather it is appropriate to say that there is negligible variation in the values of Nusselt number with the change in buoyancy parameter. There is maximum crowding of isotherms on the front surface, the value of local Nusselt number is highest on the front surface, lowest on the rear/top surface and intermediate on the left and right surface of the tapered and expanded trapezoidal cylinder. The local Nusselt number on the left and right surface is found to be identical as the flow is steady in the range of conditions covered here.

## IV. CONCLUSION

The flow and heat transfer characteristics around a tapered trapezoidal cylinder have been studied, considering the effect of aiding buoyancy (Ri=0-0.5) and Re=5-20 at Pr=0.71 under steady flow conditions. It has been observed that for fixed value of Ri, as the Reynolds number increases, the congestion of isotherms in the upstream direction increases, with the result heat transfer rate also increases. As the Reynolds number is gradually increased the flow separation takes place at the trailing edge of the cylinder which results in the formation of two symmetric standing vortices behind the obstacle at different values of Re and Ri. There is maximum crowding of isotherms on the front surface followed by top and bottom, and as such highest heat transfer on the front surface.

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