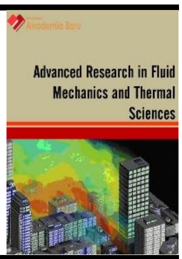
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



g-Jitter Free Convection Flow Near a Three-Dimensional Stagnation-Point Region with Internal Heat Generation

Open Access

Fakhru Ridhwan Hamdan[1], Mohamad Hidayad Ahmad Kamal[1], Noraihan Afiqah Rawi[1], Ahmad Qushairi Mohamad[1], Anati Ali[1], Mohd Rijal Ilias[2], Sharidan Shafie[1,*]

[1] Department of Mathematical Science, Faculty of Science, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[2] Department of Mathematics, Faculty of Computer and Mathematical Science, Universiti Teknologi Mara, 42300 Shah Alam, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 13 October 2019
Received in revised form 28 December 2019
Accepted 28 December 2019
Available online 15 March 2020

ABSTRACT

A numerical study on unsteady free convection viscous fluid flow on a three-dimensional stagnation point region was studied. On the flow, g-jitter effect occurs under microgravity environment and exothermic reaction causing the heat generation effect. A system of nonlinear parabolic partial differential equations was modified and introduced in this study as an extension from previous study. After semi-similar transformation technique, an implicit finite difference scheme known as the Keller-box method was imposed on the dimensionless governing equation. The analysis on profiles and physical quantities of principal interest was conducted based on the parameters considered in this flow; curvature ratio c, oscillation frequency Ω, amplitude of modulation ε, and heat generation Q. Analysis on velocity profiles shows the behavior for natural convection flow thus satisfies the boundary condition. On the other hand, different value of c produced a different special stagnation-point flow due to the different geometrical shape implies. In addition, g-Jitter effect produced a fluctuating behavior on the flow and heat transfer with larger values of Ω increased the convergence rate. From the temperature results, the temperature profile was found increased but the heat flux on the wall values decreased as Q increased. A comparison study on published result with present study shows the result on skin friction coefficient and heat flux on the wall corresponds to a very good agreement.

Keywords:
Stagnation-point flow; g-Jitter; Internal heat generation

1. Introduction

A stagnation point is defined as a point on the surface of an object within the flow field where the fluid is at rest as it hit the object [1]. Heat transfer on a three-dimensional stagnation-point flow were applied in many important applications; manufacturing process of petrochemical industries, aerodynamic of plastic sheet and solar central receivers exposed to wind currents [1]. Poots formulated a boundary-layer equation for free convection flow within a three-dimensional lower

* *Corresponding author.*
E-mail address: sharidan@utm.my (Sharidan Shafie)

stagnation point on a general curved isothermal surface, while Banks concluded that a three-dimensional solution can be exhibited on a two-dimensional stagnation point for air medium [2,3]. The study is then extended to investigate an infinitely large Prandtl number for a three-dimensional problem which is then reduced to a two-dimensional problem [4]. Kumari and Nath focused on the unsteady free convection boundary layer hydromagnetic flow near a stagnation point of a three-dimensional body with applied magnetic field and time dependent wall temperature [5]. Apart from that, a study by Bhat and Katagi has solved a mathematical model on incompressible viscous fluid problem at two-dimensional stagnation-point region with slip velocity between two porous plate using Homotopy analysis [6].

The study of heat generation in moving fluids is substantial in several physical problems dealing with chemical reactions and those concerned with dissociating fluids. Vajravelu and Hadjinicolaou studied heat transfer characteristics in the laminar boundary layer of a viscous fluid over a linearly stretching continuous surface with viscous dissipation or frictional heating and internal heat generation [7]. Chamkha and Camille solved a hydromagnetic flow with heat and mass transfer over a flat plate in the presence of heat generation or absorption and thermophoresis [8]. In addition, Mendez and Trevino analyzed the effects of a conjugate conduction-natural convection heat transfer along a thin vertical plate with non-uniform heat generation by performing asymptotic perturbation numerically using the quasi-linearization technique [9]. Mohamed studied the effects of first-order homogeneous chemical reaction on the unsteady MHD double-diffusive free convection fluid flow past a vertical porous plate [10]. The presence of heat generation observed that as the chemical parameter increased, the skin friction coefficient decreased, whereas the local Nusselt number remained unaffected.

Effect of heat generation on stagnation point flow was analyzed by Layek *et al.,* on heat and mass transfer towards a heated porous stretching sheet subjected to suction or blowing [11]. Additionally, Ahmad and Pop conducted a theoretical study on a stagnation point boundary layer nanofluid flow on a permeable stretching sheet in a porous medium in the presence of heat generation [12]. A Lie group analysis on stagnation-point flow towards a heated porous stretching sheet saturated with a nanofluid and heat absorption or generation was studied by Hamad and Ferdows [13]. For a different convective boundary condition, a study was conducted to analyse the stagnation point flow of nanofluid near a permeable stretched surface in the presence of porous medium and internal heat generation by Alsaedi *et al.,* [14]. Studies on the engineering application problem which closely related to endothermic and exothermic reaction caused by chemical reaction were also being studied [15-18].

g-Jitter is defined as an inertia effect due to quasi-steady, oscillatory or transient accelerations arising from crew's motions and machine vibrations in a parabolic aircraft, space shuttle or other microgravity environment [19]. Langbein conducted an experimental study on g-jitter induced free convection from a sphere which concluded that the solidification of isotherm should use a certain value to avoid striations of growing crystals [20]. Rees and Pop then investigated the effects of g-jitter on vertical free convection boundary layer flow in a porous media numerically [21]. The result eventually confined to a thin layer embedded within the main boundary layer and it showed that g-jitter becomes weak with an increase of distance from the leading edge. Meanwhile, Pan *et al.,* presented a mathematical modelling that analysed numerically on the magnetic damping of g-jitter driven fluid flow and its effect on the solute element distributions in a simplified Bridgman-Stockbarger crystal growth system under microgravity environment [22].

Sharidan *et al.,* examined the effects of g-jitter induced free convection boundary layer flow near a three-dimensional stagnation point of attachment numerically [23]. The problem was then numerically extended to a non-Newtonian micropolar fluid near a three-dimensional stagnation point region induced by g-jitter [24]. By using enhanced fluid on the flow, Kamal *et al.,* extended the study in three-dimensional stagnation point flow for heat and mass transfer properties [25]. As for boundary layer flow induced by g-jitter and heat generation, Chamkha conducted a study in analysing behaviour of a simple system consisting of two parallel impermeable infinite plates with g-jitter, transverse magnetic field and heat generation at four different thermal boundary conditions [26]. Bhaduria *et al.,* later presented a study on heat transport in a porous medium under the combined effect of internal heating and time-periodic gravity modulation [27]. Consequently, this present study of g-jitter effects on unsteady free convection boundary layer flow at a three-dimensional stagnation point region induced by internal heat generation will be highlighted.

2. Methodology
2.1 Mathematical Model

Consider the unsteady free convection flow near the stagnation point of a heated three-dimensional body with effects of heat generation placed in a viscous and incompressible fluid of uniform temperature T_∞. It is assumed that the uniform temperature of the body suddenly changes from T_w to T_∞, where $T_w > T_\infty$. A locally Cartesian orthogonal system (x, y, z) is chosen with the origin **N** at the nodal stagnation point as shown in Figure 1, where the $x-$ and $y-$coordinates are measured along the body surface, while the $z-$coordinate is measured normal to the body surface.

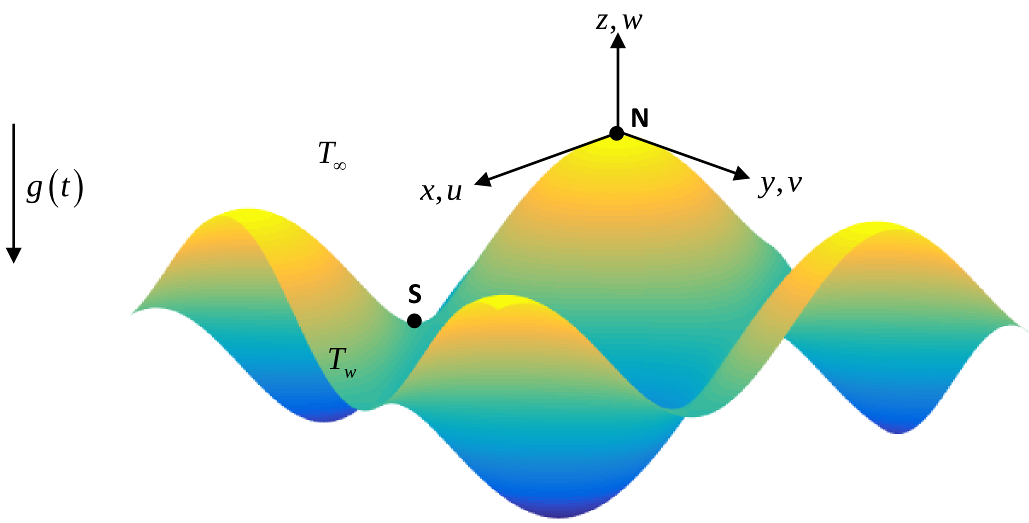


Fig. 1. Physical model on Cartesian coordinate system

Consider gravity vector $g^*(t)$ is normal to the surface at $x=0$ and $y=0$. Under a microgravity environment, a fluctuating gravitational field was defined as [23],

$$g^*(t) = g_0\left[1+\varepsilon\cos(\pi\omega t)\right] \tag{1}$$

where g_0 is the mean gravitational acceleration, ε is the amplitude of modulation and ω is the frequency of g-jitter, **k** is the unit vector acting opposite to the $z-$direction and t is time. With this assumption, the governing equation of free convection boundary layer flow induced by g-jitter and internal heat generation assumed as [23,28],

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{2}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=\upsilon\frac{\partial^2 u}{\partial z^2}+g^*(t)\beta ax\left(T-T_\infty\right) \tag{3}$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=\upsilon\frac{\partial^2 v}{\partial z^2}+g^*(t)\beta by\left(T-T_\infty\right) \tag{4}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha\frac{\partial^2 T}{\partial z^2}+\frac{Q_0}{\rho C_p}\left(T-T_\infty\right) \tag{5}$$

subject to the initial and boundary conditions

$$\begin{aligned} &t<0: u=v=w=0, T=T_\infty \text{ for any } x, y \text{ and } z,\\ &t\geq 0: u=v=w=0, T=T_w \text{ on } z=0, x\geq 0, y\geq 0,\\ &\qquad u=v=w=0, T=T_\infty \text{ as } z\to\infty, x\geq 0, y\geq 0. \end{aligned} \tag{6}$$

Here u, v, w are the velocity components along the $x-, y-, z-$ axes, T is the fluid temperature, g is the magnitude of the gravity acceleration, α is the coefficient of thermal diffusivity, υ is the kinematic viscosity, β is the volumetric coefficient of thermal expansion, a and b are the parameters of the principal curvatures at **N** of the body measured in the planes x and y respectively. There is no loss of generality that requires $|a|\geq|b|$ with $a>0$. Clearly $b=0$ corresponds to the plane stagnation flow case, while $b=a$ is the axisymmetric case. We assume here that a and b are positive so that solutions of the resulting equations lead to a stagnation point which are nodal points of attachment, i.e. $0\leq c\leq 1$, where $c=b/a$. However, a or b could also be negative which are the saddle points of attachment, i.e. $-1\leq c\leq 0$. Since most shapes of practical interest lie between cylinder $(c=0)$ and sphere $(c=1)$, we shall confine our analysis to nodal points of attachment only $(0\leq c\leq 1)$. Semi-similar transformation technique implies on Eq. (2) to Eq. (6) using semi-similar variables in Eq. (7) such that [23,29],

$$\begin{aligned} &\tau=\Omega t, \quad \eta=Gr^{1/4}az, \quad t=va^2Gr^{1/2}t^*,\\ &u=va^2xGr^{1/2}f'(t,\eta), \quad v=va^2yGr^{1/2}h'\left(t,\eta\right), \quad w=-vaGr^{1/4}(f+h),\\ &\theta(t,\eta)=\frac{(T-T_\infty)}{(T_w-T_\infty)}, \quad \Omega=\frac{\omega}{va^2Gr^{1/2}}, \quad g(t)=\frac{g^*(t^*)}{g_0}, \end{aligned} \tag{7}$$

where $Gr=g_0\beta\left(T_w-T_\infty\right)/\left(a^3\upsilon^2\right)$ is the Grashof number and primes denote represents partial differential equation with respect to η. Eq. (2) to Eq. (6) undergo semi-similar transformation technique using Eq. (7) and produced a system of non-dimensional partial differential equation such that,

$$f'''+(f+h)f''-f'^2+\theta\left[1+\varepsilon\cos(\pi\tau)\right]=\Omega\frac{\partial f'}{\partial\tau} \tag{8}$$

$$h'''+(f+h)h''-h'^2+c\theta\left[1+\varepsilon\cos(\pi\tau)\right]=\Omega\frac{\partial h'}{\partial\tau} \tag{9}$$

$$\frac{1}{\Pr}\theta''+(f+h)\theta'-Q\theta=\Omega\frac{\partial\theta}{\partial\tau} \tag{10}$$

subject to boundary condition

$$\begin{aligned} &f(\tau,0)=f'(\tau,0)=0,\\ &h(\tau,0)=h'(\tau,0)=0,\\ &\theta(\tau,0)=1,\\ &f'\to 0\quad h'\to 0\quad \theta\to 0\quad \text{as}\quad \eta\to\infty \end{aligned} \tag{11}$$

where $Q=\dfrac{Q_0}{\rho C_p \upsilon a^2 Gr^{\frac{1}{2}}}$

The physical quantities of principal interest analysed in this problem are wall skin friction coefficient C_{fx} and C_{fy} together with local Nusselt number, Nu is defined as

$$\begin{aligned} C_{fx}&=\mu\left(\frac{\partial u^*}{\partial z^*}\right)_{z^*=0}\Big/\left(\rho_f {v_f}^2 a^3 x^*\right)\\ C_{fy}&=\mu\left(\frac{\partial v^*}{\partial z^*}\right)_{z^*=0}\Big/\left(\rho_f {v_f}^2 a^3 y^*\right)\\ Nu&=a^{-1}\left(\frac{\partial T}{\partial z^*}\right)_{z^*=0}\Big/\left(T_w-T_\infty\right) \end{aligned} \tag{12}$$

where ρ and μ are the density and dynamic viscosity, respectively. By using Eq. (7), Eq. (12) becomes a non-dimensional physical quantity such as,

$$\begin{aligned} C_{fx}/Gr^{3/4}&=f''(\tau,0)\\ C_{fy}/Gr^{3/4}&=h''(\tau,0)\\ Nu/Gr^{1/4}&=-\theta'(\tau,0) \end{aligned} \tag{13}$$

2.2 Method of Solution

The system of the dimensionless partial differential equations, Eq. (8) to Eq. (10) together with the boundary conditions Eq. (11) were solved numerically using an implicit finite scheme known as Keller-box method. The partial differential equations will first be reduced to a first order and discretized by using central difference. Then, Newton's method is used to linearize the resulting equation and then employed into a coefficient matrix and becomes a system of finite different equations. Finally, the linear system is solved using block tridiagonal elimination method.

All the results were obtained using uniform grids in both τ and η direction with $\Delta\tau = 0.1$ and $\Delta\eta = 0.04$. A solution converges when the maximum absolute point change between iteration is 10^{-10}. The detailed results are presented for the amplitude of the gravity modulation in the range $0 < \varepsilon < 1$, frequency of the single-harmonic components of oscillation is 0.2 and 5, and the curvature ratio at the stagnation point c values are $0, 0.5$ and 1. The results are then presented graphically corresponding to the effect for each parameter and discussed briefly.

3. Results

Results were obtained from the systems of equation that have been solved numerically using Keller-box method. The solution begins when a stagnation-point near $x = 0$ with initial boundary which then proceeds to the boundary layer of stagnation point region. The results of the present study show a very good agreement with previous study by Sharidan *et al.,* [23] shown in Table 1.

Table 1
Comparison of reduced skin frictions and heat transfer rate for $\varepsilon = 1, \Pr = 0.72, \Omega = 0.2$ and various value of c

	Sharidan *et al.,* [23]			Present		
c	0	0.5	1	0	0.5	1
$f''(0)$	0.824202	0.765179	0.730998	0.823456	0.766882	0.732769
$h''(0)$	0	0.410019	0.730998	0	0.410794	0.732769
$-\theta'$	0.357429	0.407123	0.437107	0.35752	0.40710	0.43719

The analysis was conducted on velocity and temperature profiles with different values of heat generation parameter Q, curvature ratio c, and frequency of oscillation Ω as presented in Figure 2 to 4. Constant values for other parameter were chosen such that Prandtl number $\Pr = 0.72$ which represent air medium and amplitude of modulation $\varepsilon = 0.3$ respectively. Figure 2 presents the velocity and temperature profiles results for $c = 0$, $\Omega = 0.2, 5$ and $Q = 0, 1, 2$ with respect to boundary layer thickness η. As values for Q increased, the results of velocity profile on $x-$direction f' decreased for $\Omega = 0.2$. A contradict behaviour was noticed on temperature profile θ in which the temperature increased as Q increased. Besides that, the same behaviour on f' and θ was noticed even for larger size of frequency $\Omega = 5$. By comparing the profiles results for the different Ω size, smaller Ω produced larger value of f' and θ. An interesting behaviour was identified on velocity profile in $y-$direction h', for $c = 0$. For both sizes of Ω, there was no changes on h' as Q increased. A small conclusion was made that heat generation parameter provide a significant effect on the flow pattern.

Figure 3 illustrates the profiles of f', h' and θ for different Q and Ω parameter values. From the graph analysed, velocity profiles f' and h' decreased as Q value increased while θ increased for $\Omega = 0.2$. As for $\Omega = 5$, the flow and heat properties behave the same way with smaller sizes but have a bigger magnitude values in term of profile. In this figure, the behaviour of h' are not the same as h' in Figure 2 as there is significant changes with the increased of Q. Heat generation effect are considered in boundary layer flow as there is heat source produced inside of the fluid flow that also known as exothermic phenomena. In contrast, an endothermic is a phenomenon that occurred as heat sink was produced from chemical reaction on the fluid. In this study, heat generation effect was considered, thus there will be an additional heat sources that contribute to

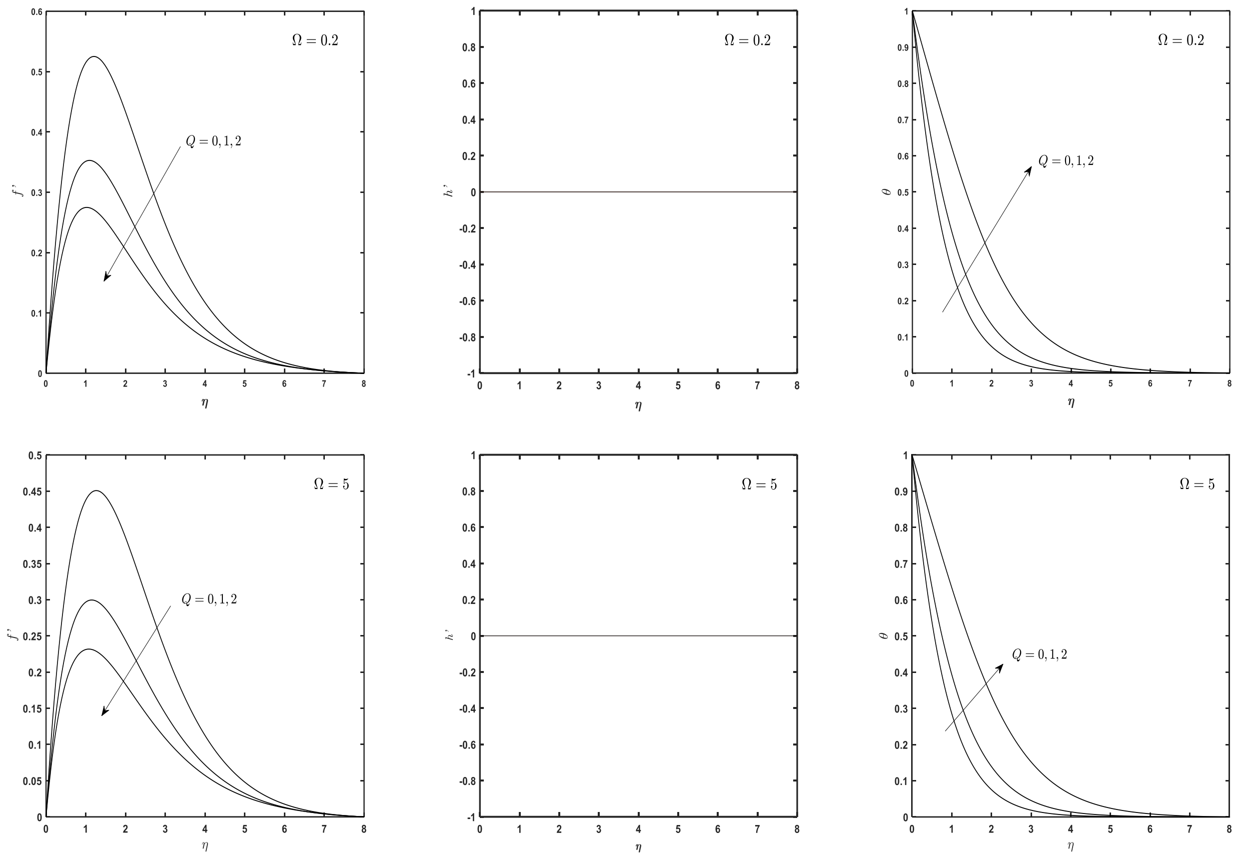


Fig. 2. The variation of velocity profiles f', h' and temperature profiles θ on the effect of Q and Ω with constant $c = 0$ and $\varepsilon = 0.3$

the fluid. The extra heat sources will increase the heat enhancement properties of the fluid as shown in the increased of θ values. From the literature, the presence of Q on boundary layer flow were known significantly affecting the sheer stress fluid motion. Thus, profiles on f' and h' were increased as sheer stress raised with the presence of Q in boundary layer flow.

Analysis on f', h' and θ profiles were presented in Figure 4 with constant ε and c with different values of Q and Ω. The same behaviour was noticed on flow and temperature profiles as discussed in Figures 2 and 3. Velocity profiles on the same frequency of oscillation size provide an interesting behaviour to be analysed. The value for both velocity profiles on f' and h' were found to be the same in term of magnitude as η increased at $c = 1$. Aside from that, the pattern produced by the profiles revealed the typical profiles for natural convection boundary layer flow. For the velocity profiles on f' and h', there was no movement at the boundary wall, and the value increased to the peak values as η increased. The velocity profiles were finally approached to zero as η increased larger or to infinity. Besides that, the θ pattern also followed the behaviour of free convection boundary layer flow with the temperature profile gradually decreased with the increased of η. The precision of our model and solving method implied in this problem were also supported based on the profiles results on f', h' and θ that satisfied the boundary condition of the proposed model.

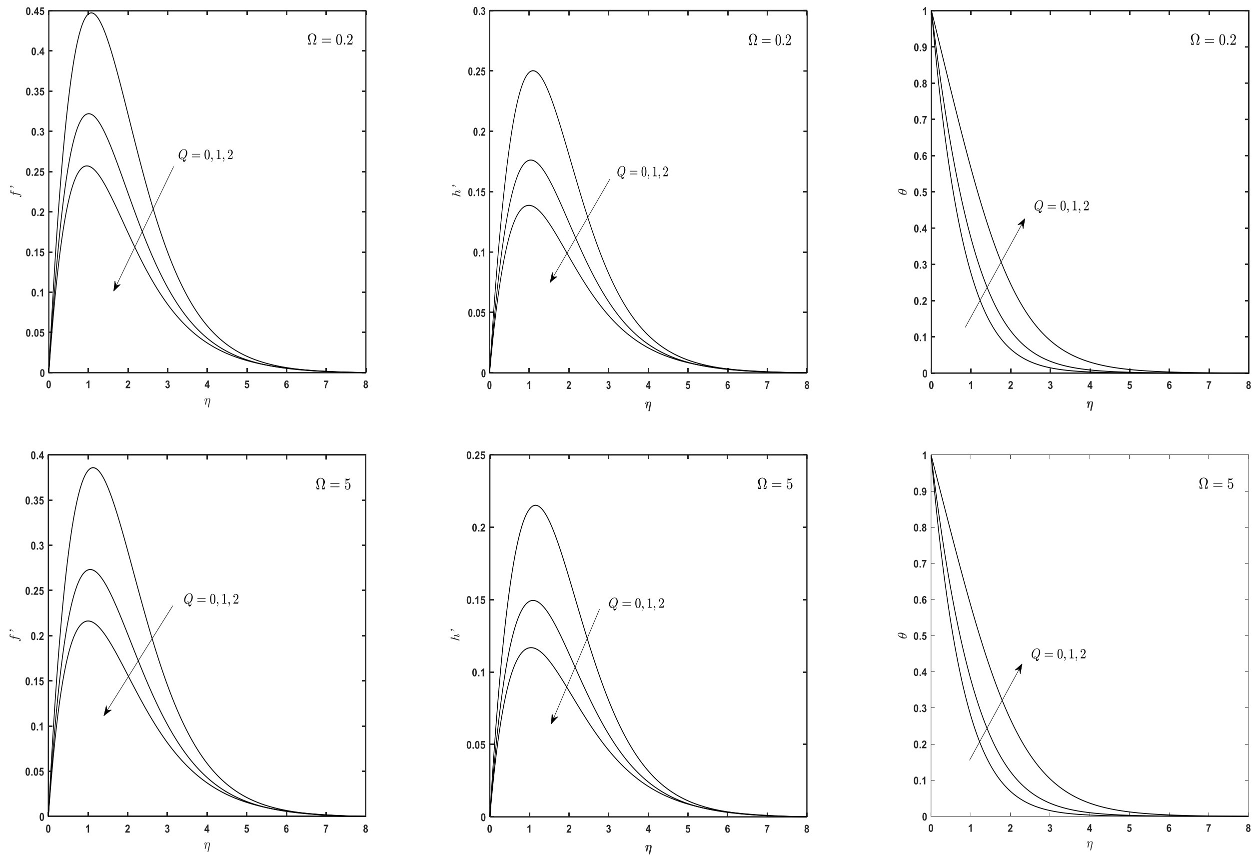


Fig. 3. The variation of velocity profiles f', h' and temperature profiles θ on the effect of Q and Ω with constant $c = 0.5$ and $\varepsilon = 0.3$

As a part of the analysis conducted in this study, physical quantities of principal interest has also been analysed for skin friction coefficient on $x-$direction f'' and $y-$direction h'' together with heat flux on the wall $-\theta'$ as presented in Figure 5 to 10. The results of f'', h'' and $-\theta'$ on $c = 0$ with different value of Q and $\Omega = 0.2$ is illustrated in Figure 5 while larger size of Ω with $\Omega = 5$ is presented in Figure 6. In each graph, a fluctuation behaviour is noticed on each of the physical quantity studied as the values of ε increased. It is worth to mention that the range for ε was selected based on g-jitter properties that reversed it direction as $\varepsilon > 1$. In analysing the effect of Q in Figures 5 and 6, larger values of Q increased the values of f'' and h'' while decreased the value of $-\theta'$. As the effect of heat generation considered in this problem, there are heat sources produced inside the fluid caused by chemical reaction phenomena. Since there is heat produced inside of the fluid, the rate of heat transfer from the body wall to the fluid or known as heat flux $-\theta'$ were also reduced. Besides that, the graph presenting skin friction on h'' in Figures 5 and 6 did not change as the time τ and ε increased for all values of Q. Values chosen for c were actually represent the geometrical shape of boundary body. Here, $c = 0$ represents the cylindrical geometrical shape that contributes to no significant changes on h''. From the literature, as h'' did not change, a special type of flow known as plane stagnation-point flow.

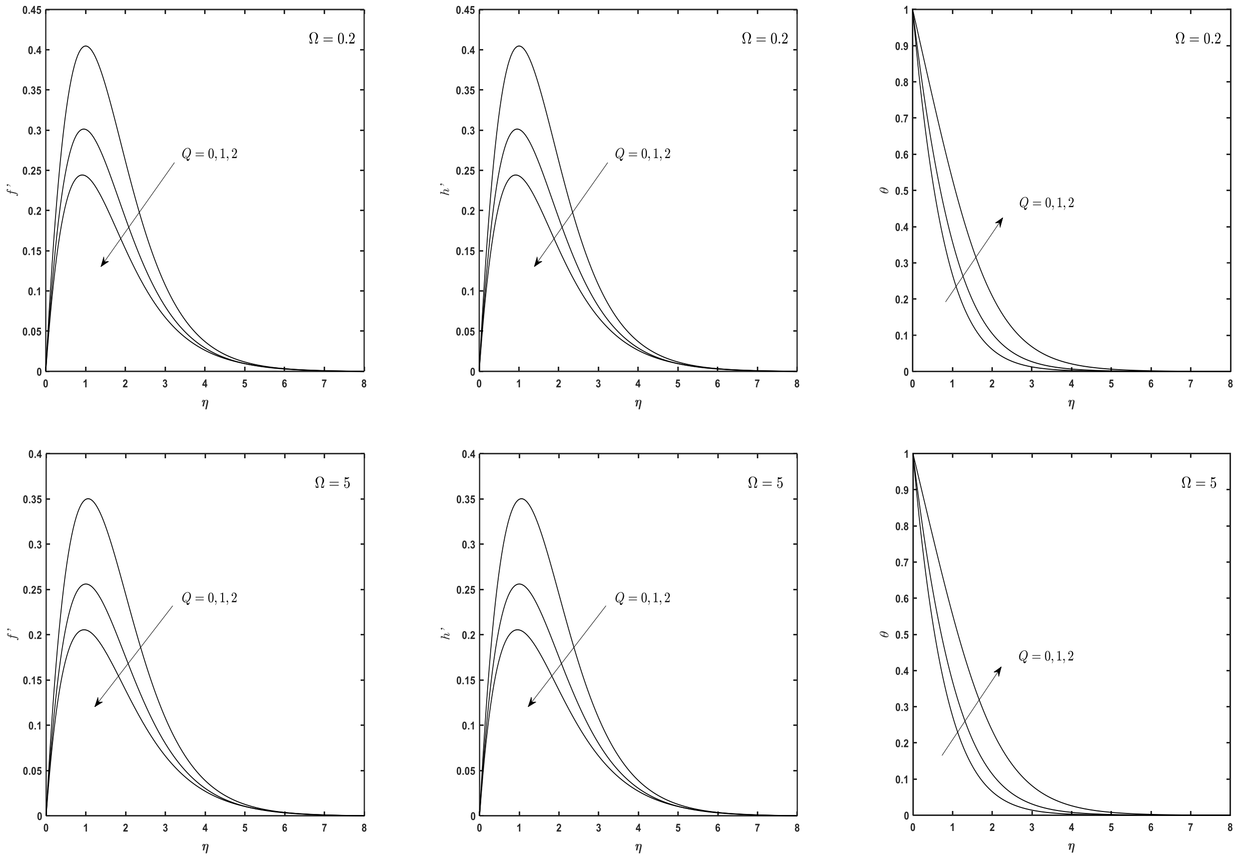


Fig. 4. The variation of velocity profiles f', h' and temperature profiles θ on the effect of Q and Ω with constant $c = 1.0$ and $\varepsilon = 0.3$

Different values of c were analysed in Figures 7 and 8 with constant $c = 0.5$ and $\Pr = 0.72$ that represent the air medium. Fluctuation behaviour is noticed in all physical quantities including on h'' that did not change in Figures 5 and 6. The effect of Q showed the same behaviour as before on f'', h'' and $-\theta'$ when Q values increased. By comparing the effect of Ω in Figures 7 and 8, larger value of Ω were able to reduce the peak values on all physical quantities and more significantly on $-\theta'$ as compared on f'' and h''. From the analysis, we may conclude that larger values of Ω may increase the converge rate of the problem. Other than that, the magnitude of h'' was found to be smaller than f'' for the same values of Ω and Q. The analysis results also show that increased of Q increased the values of skin frictions in both direction f'' and h''. As discussed before in the velocity profile result was reduced in the presence of Q due to the contribution to the rise of sheer stress on the fluid motion. Additional frictional force was experienced at the boundary layer surface due to the rise of sheer stress which contribute to the rise of f'' and h''. A small conclusion could be made in which that the presence of heat generation effect provides a very significant effect on flow and temperature characteristics.

Figures 9 and 10 show the results of skin frictions f'' and h'' together with heat flux on the wall $-\theta'$ for parameter $c = 1$. Figure 9 presents an analysis of the physical quantities for smaller

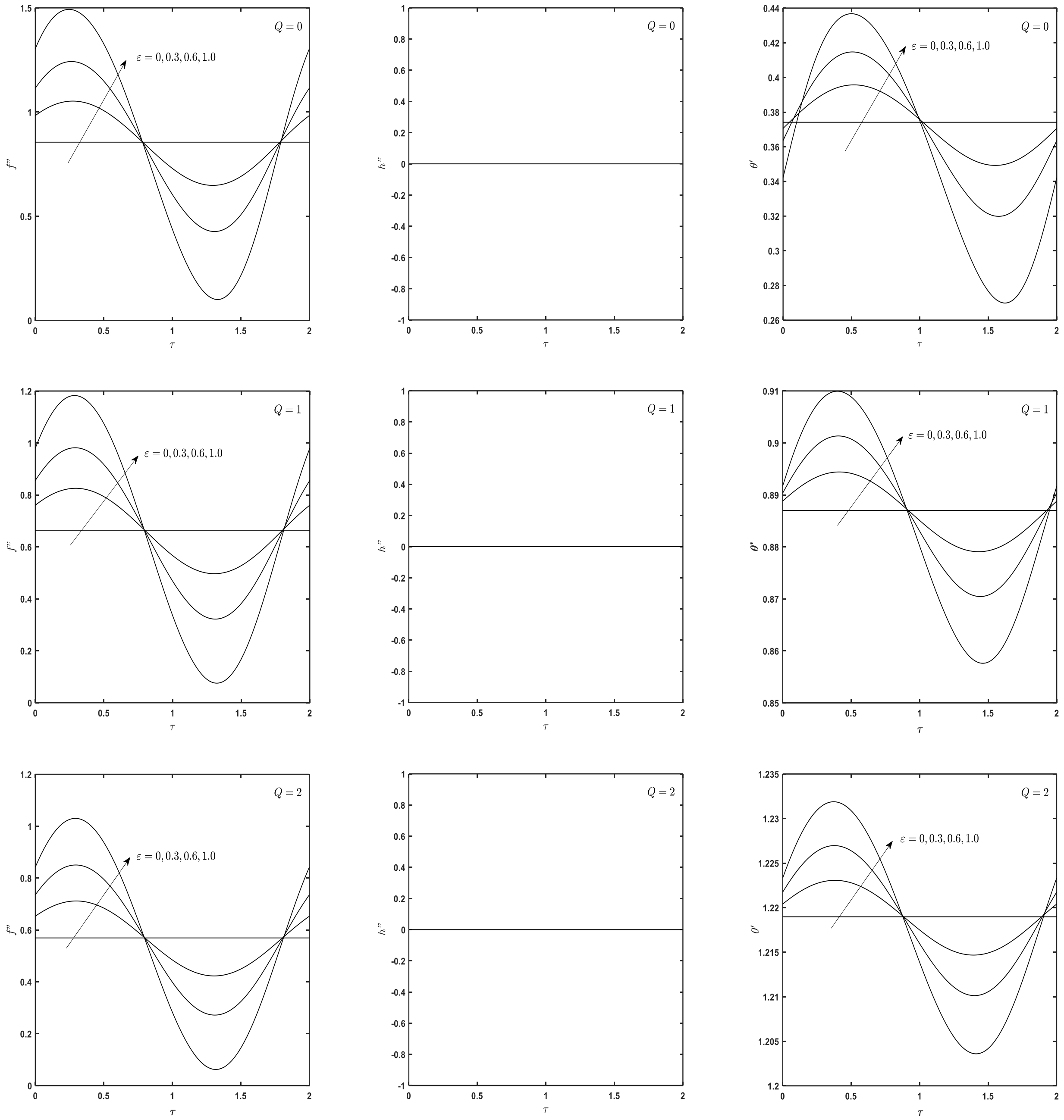


Fig. 5. The variation of skin friction coefficients f'', h'' and heat flux on the wall $-\theta'$ on the effect of Q and ε with constant $c = 0$ and $\Omega = 0.2$

size of frequency of oscillation $\Omega = 0.2$ while Figure 10 presents the analysis for bigger sizes with $\Omega = 5$. The increased of parameter Q on physical quantities f'', h'' and $-\theta'$ were found to be the same in Figure 5 to 8. As for Ω, larger values of Ω increased the convergence rate as discussed in Figure 5 to 8. In addition, for $\varepsilon = 0$ a fluctuation behaviour did not occur at this condition on all physical quantities studied. Steady state condition was considered when the problem did not

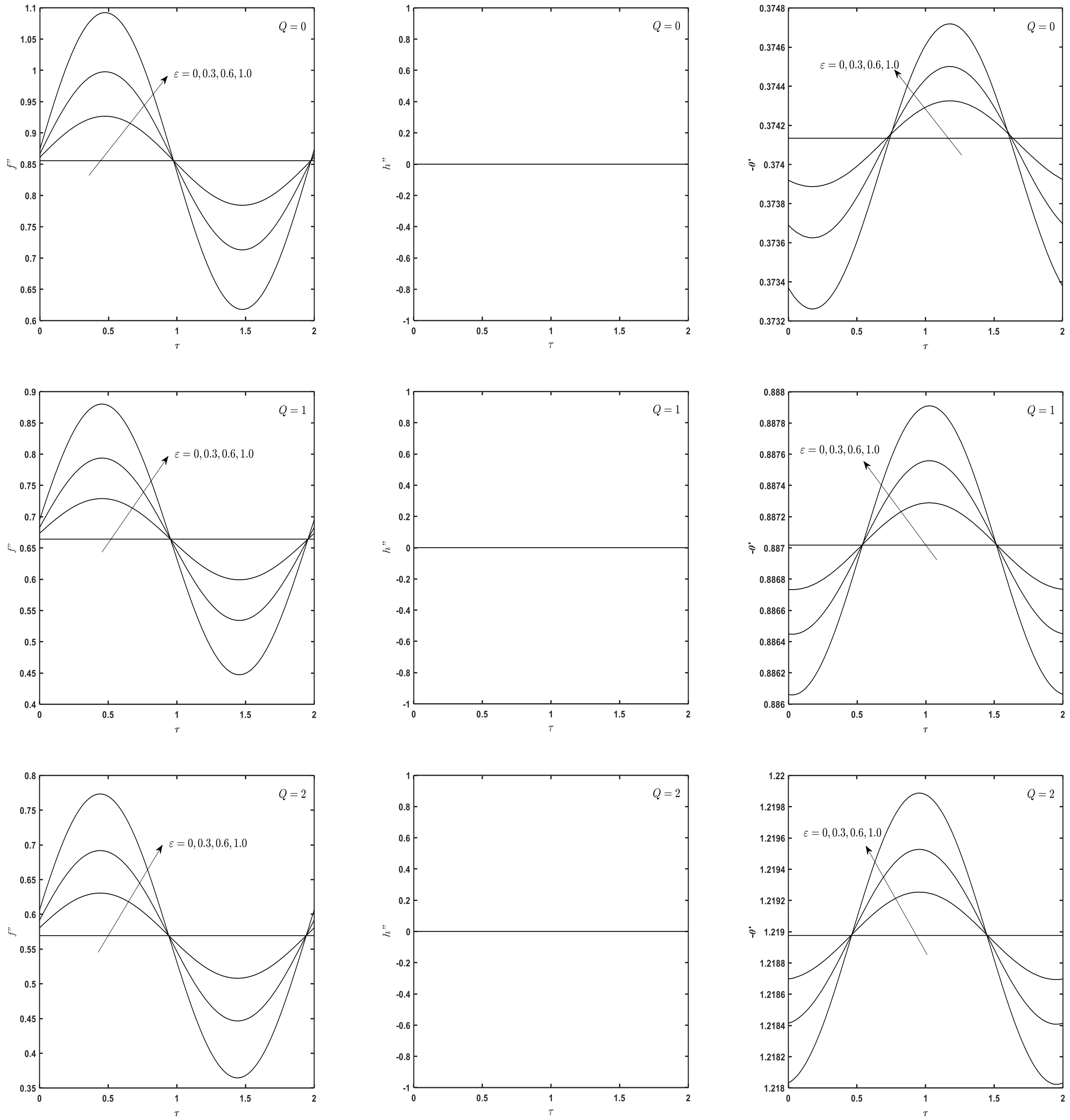


Fig. 6. The variation of skin friction coefficients f'', h'' and heat flux on the wall $-\theta'$ on the effect of Q and ε with constant $c=0$ and $\Omega=5$

depend on t and in our study occurs at $\varepsilon=0$. g-Jitter is an effect that occurs under unsteady condition only, thus in certain cases fluctuation gravitational field did not occur. In addition, the highest peak values for every physical quantity studied f'', h'' and $-\theta'$ occurs at $\varepsilon=1$. It is interesting to discuss that the result of skin frictions in Figures 9 and 10 have the same values of f''

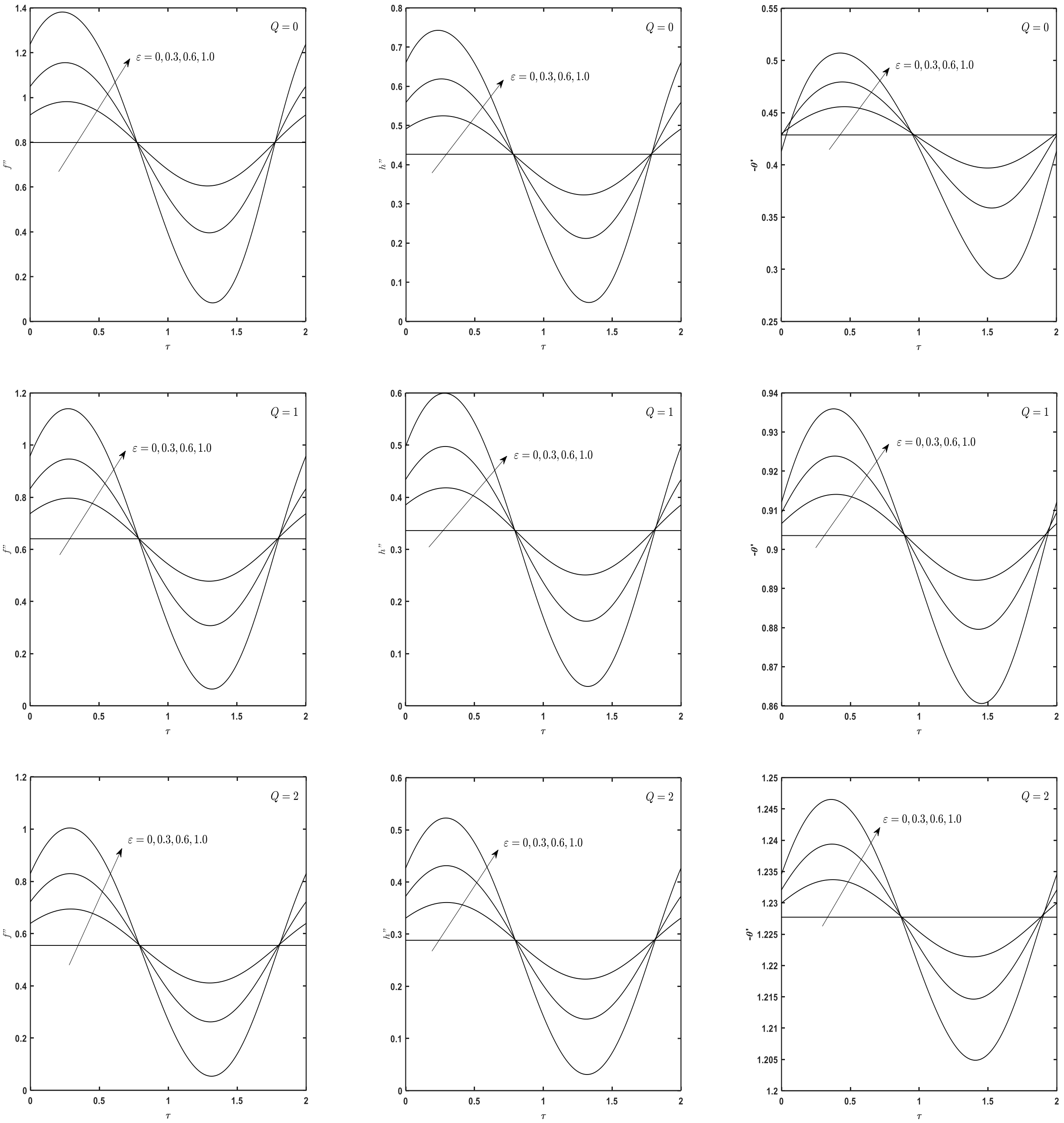


Fig. 7. The variation of skin friction coefficients f'', h'' and heat flux on the wall $-\theta'$ on the effect of Q and ε with constant $c=0.5$ and $\Omega=0.2$

and h'' at any t. At parameter $c=1$, values for f'' and h'' were found to be the same which caused by the geometrical shape body. Spherical boundary geometrical shape was represented by $c=1$ and caused a special stagnation-point flow. An axisymmetric stagnation-point flow was produced as skin fiction f'' and h'' having the same values as presented in Figures 9 and 10.

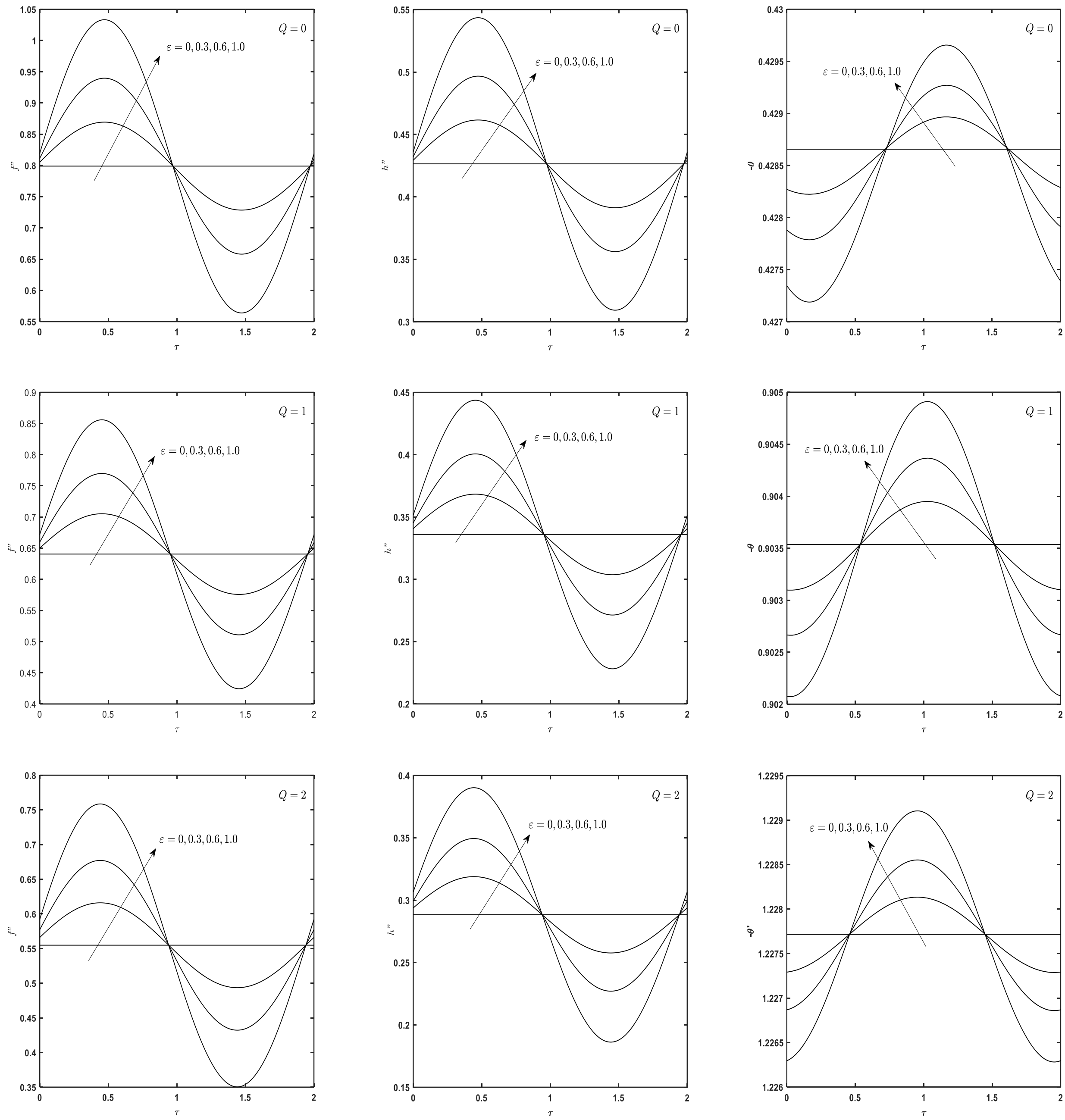


Fig. 8. The variation of skin friction coefficients f'', h'' and heat flux on the wall $-\theta'$ on the effect of Q and ε with constant $c=0.5$ and $\Omega=5$

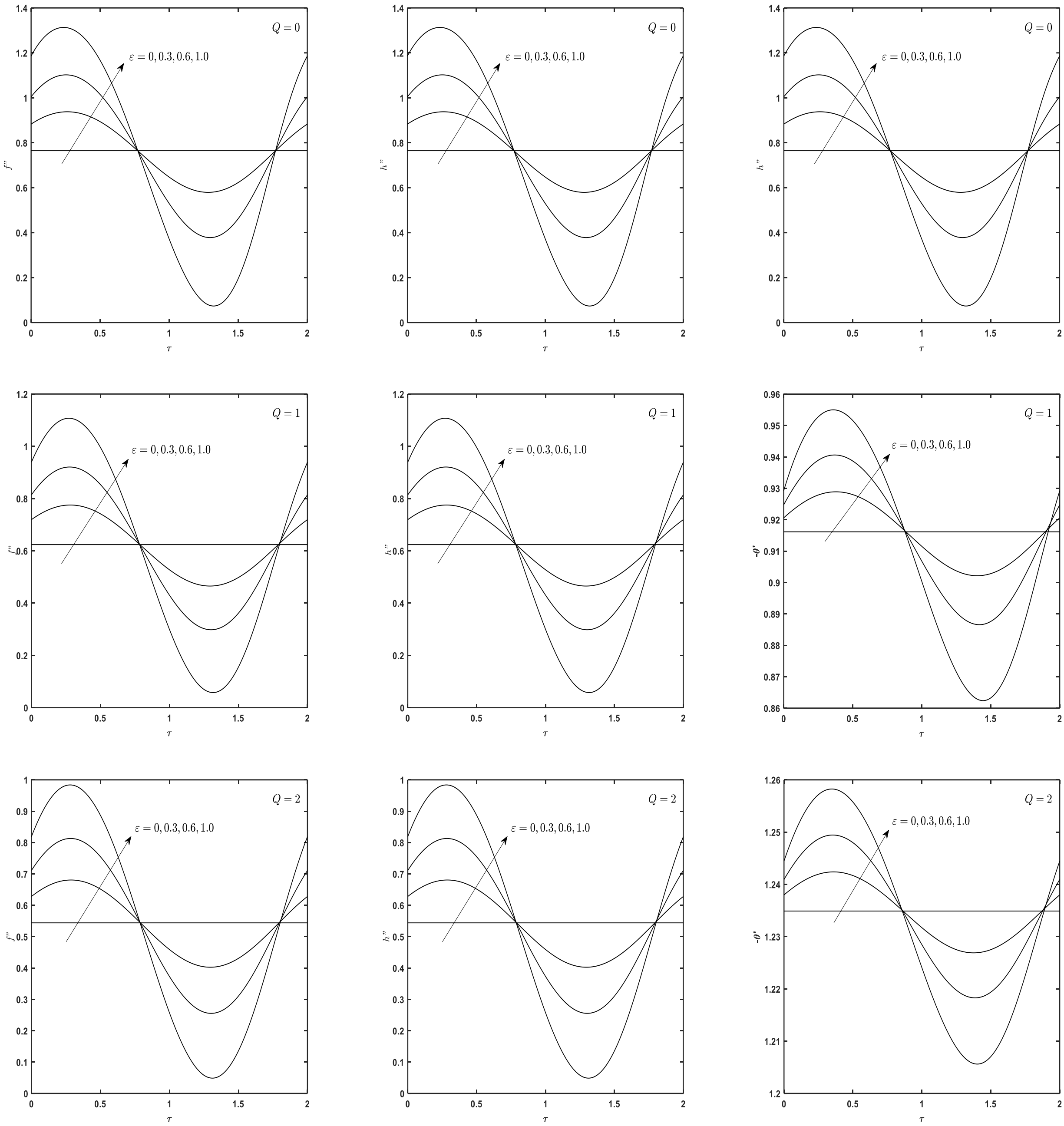


Fig. 9. The variation of skin friction coefficients f'', h'' and heat flux on the wall $-\theta'$ on the effect of Q and ε with constant $c = 1.0$ and $\Omega = 0.2$

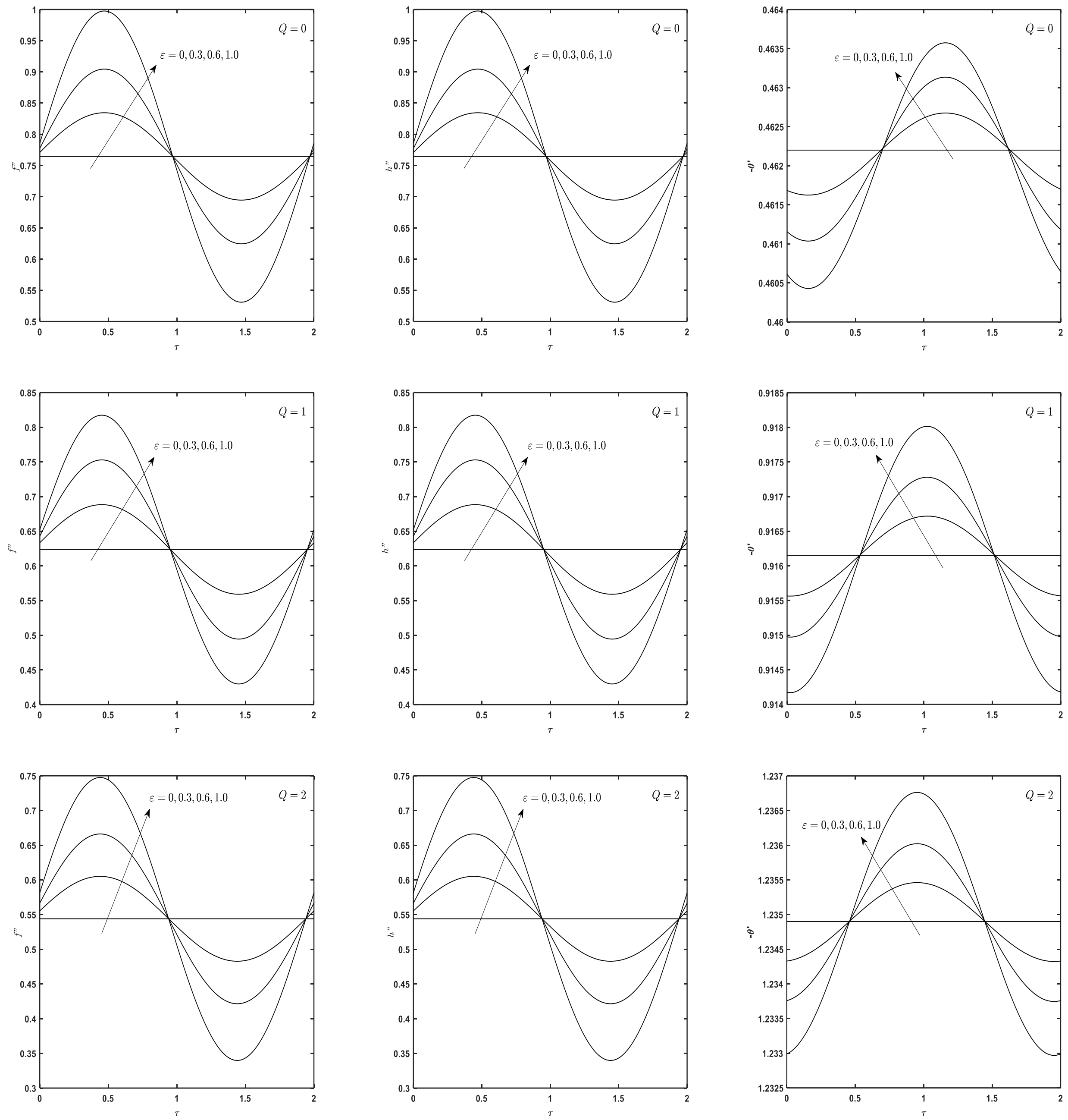


Fig. 10. The variation of skin friction coefficients f'', h'' and heat flux on the wall $-\theta'$ on the effect of Q and ε with constant $c = 1.0$ and $\Omega = 5$

4. Conclusions

A fundamental study on three-dimensional stagnation-point boundary layer flow with internal heat generation under microgravity environment was successfully conducted. A modified system of partial differential equation that were introduced and analysed numerically in term of profiles and physical quantities. Based on analysis, it can be concluded that

1. The presence of Q in boundary layer flow increased f'', h'' and θ but decreased the f', h' and $-\theta'$.
2. Different values of c produced different types of stagnation-point flow.
3. The highest peak values of physical quantities were produced at $\varepsilon = 1$.

4. Larger value of Ω increased the convergence rate of the stagnation-point flow.

Acknowledgement
The authors would like to acknowledge Ministry of Education (MOE) and Research Management Centre-UTM, Universiti Teknologi Malaysia (UTM) for the financial support through vote numbers 5F004, 5F116, 07G70, 07G72, 07G76, 07G77 and 17J98 for this research.

References

[1] Farooq, Umer, and Hang Xu. "Free convection nanofluid flow in the stagnation-point region of a three-dimensional body." *The Scientific World Journal* 2014 (2014): 1-14.
[2] Poots, G. "Laminar free convection near the lower stagnation point on an isothermal curved surface." *International Journal of Heat and Mass Transfer* 7, no. 8 (1964): 863-874.
[3] Banks, W. H. H. "Laminar free convection flow at a stagnation point of attachment on an isothermal surface." *Journal of Engineering Mathematics* 8, no. 1 (1974): 45-56.
[4] Banks, W. H. H. "Three-dimensional free convection flow near a two-dimensional isothermal surface." *Journal of Engineering Mathematics* 6, no. 2 (1972): 109-115.
[5] Kumari, M., and G. Nath. "Unsteady free convection MHD boundary layer flow near a three-dimensional stagnation point." *Indian Journal of Pure and Applied Mathematics* 17, no. 7 (1986): 957-968.
[6] Bhat, Ashwini, and Nagaraj N. Katagi. "Analysis of Stagnation Point flow of an Incompressible Viscous Fluid between Porous Plates with Velocity Slip." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 48, no. 1 (2018): 40-52.
[7] Vajravelu, K., and A. Hadjinicolaou. "Heat transfer in a viscous fluid over a stretching sheet with viscous dissipation and internal heat generation." *International Communications in Heat and Mass Transfer* 20, no. 3 (1993): 417-430.
[8] Chamkha, Ali J., and Camille Issa. "Effects of heat generation/absorption and thermophoresis on hydromagnetic flow with heat and mass transfer over a flat surface." *International Journal of Numerical Methods for Heat & Fluid Flow* 10, no. 4 (2000): 432-449.
[9] Mendez, F., and C. Trevino. "The conjugate conduction–natural convection heat transfer along a thin vertical plate with non-uniform internal heat generation." *International Journal of Heat and Mass Transfer* 43, no. 15 (2000): 2739-2748.
[10] Mohamed, R. A. "Double-diffusive convection-radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and Soret effects." *Applied mathematical sciences* 3, no. 13 (2009): 629-651.
[11] Layek, G. C., S. Mukhopadhyay, and Sk A. Samad. "Heat and mass transfer analysis for boundary layer stagnation-point flow towards a heated porous stretching sheet with heat absorption/generation and suction/blowing." *International communications in heat and mass transfer* 34, no. 3 (2007): 347-356.
[12] Hamad, M. A. A., and I. Pop. "Scaling transformations for boundary layer flow near the stagnation-point on a heated permeable stretching surface in a porous medium saturated with a nanofluid and heat generation/absorption effects." *Transport in Porous Media* 87, no. 1 (2011): 25-39.
[13] Hamad, M. A. A., and M. Ferdows. "Similarity solution of boundary layer stagnation-point flow towards a heated porous stretching sheet saturated with a nanofluid with heat absorption/generation and suction/blowing: a Lie group analysis." *Communications in Nonlinear Science and Numerical Simulation* 17, no. 1 (2012): 132-140.
[14] Alsaedi, A., M. Awais, and T. Hayat. "Effects of heat generation/absorption on stagnation point flow of nanofluid over a surface with convective boundary conditions." *Communications in Nonlinear Science and Numerical Simulation* 17, no. 11 (2012): 4210-4223.
[15] Siddique, Umair, Emaad Ansari, Sher Afghan Khan, and Rajesh Patil. "On Numerical Investigation of Nusselt Distribution Profile of Heat Sink Using Lateral Impingement of Air Jet." *CFD Letters* 11, no. 9 (2019): 59-68.
[16] Muhammad, Nura Mu'az, Nor Azwadi Che Sidik, Aminuddin Saat, and Bala Abdullahi. "Effect of Nanofluids on Heat Transfer and Pressure Drop Characteristics of Diverging-Converging Minichannel heat sink." *CFD Letters* 11: 105-20.
[17] Qin, Yap Zi, Amer Nordin Darus, Che Sidik, and Nor Azwadi. "Numerical analysis on natural convection heat transfer of a heat sink with cylindrical pin fin. Vol. 695." *Trans Tech Publications* (2015).
[18] Noh, N. M., A. Fazeli, and NA Che Sidik. "Numerical simulation of nanofluids for cooling efficiency in microchannel heat sink." *J. Adv. Res. Fluid Mech. Therm. Sci.* 4, no. 1 (2014): 13-23.
[19] Rawi, Noraihan Afiqah, Abdul Rahman Mohd Kasim, Mukheta Isa, and Sharidan Shafie. "G-Jitter induced mixed convection flow of heat and mass transfer past an inclined stretching sheet." *Jurnal Teknologi* 71, no. 1 (2014): 27-31.

[20] Langbein, Dieter. "Motion of Ensembles of Spherical Particles in a Fluid Due to g-jitter." *Advances in Space Research* 11, no. 7 (1991): 189-196.
[21] Rees, D. Andrew S., and I. Pop. "The effect of g-jitter on vertical free convection boundary-layer flow in porous media." *International communications in heat and mass transfer* 27, no. 3 (2000): 415-424.
[22] Pan, Bo, D. Y. Shang, B. Q. Li, and H. C. De Groh. "Magnetic field effects on g-jitter induced flow and solute transport." *International journal of heat and mass transfer* 45, no. 1 (2002): 125-144.
[23] Shafie, Sharidan, Norsarahaida Amin, and Ioan Pop. "g-Jitter free convection flow in the stagnation-point region of a three-dimensional body." *Mechanics Research Communications* 34, no. 2 (2007): 115-122.
[24] Shafie, Sharidan, Norsarahaida Saidina Amin, and Ioan Pop. "G-Jitter free convection boundary layer flow of a micropolar fluid near a three-dimensional stagnation point of attachment." *International Journal of Fluid Mechanics Research* 32, no. 3 (2005): 291-309.
[25] Kamal, Mohamad Hidayad Ahmad, Noraihan Afiqah Rawi, Anati Ali, and Sharidan Shafie. "G-Jitter Induced Natural Convection Nanofluid Flow with Mass Transfer in The Stagnation Point Region of a Three Dimensional Body." In *Journal of Physics: Conference Series* 1366, no. 1, (2019): 12-36.
[26] Chamkha, Ali J. "Effects of heat generation on g-jitter induced natural convection flow in a channel with isothermal or isoflux walls." *Heat and mass transfer* 39, no. 7 (2003): 553-560.
[27] Bhadauria, B. S., Ishak Hashim, and P. G. Siddheshwar. "Study of heat transport in a porous medium under G-jitter and internal heating effects." *Transport in porous media* 96, no. 1 (2013): 21-37.
[28] Admon, Mohd Ariff, Abdul Rahman Mohd Kasim, and Sharidan Shafie. "Unsteady free convection flow over a three-dimensional stagnation point with internal heat generation or absorption." *World Acad. Sci., Eng. Technol* 51 (2011): 530-535.
[29] Kamal, Mohamad Hidayad Ahmad, Anati Ali, and Sharidan Shafie. "g-Jitter Free Convection Flow of Nanofluid in The Three-Dimensional Stagnation Point Region." *MATEMATIKA: Malaysian Journal of Industrial and Applied Mathematics* 35, no. 2 (2019): 260-270.