International Journal of Advanced Engineering and Management Research

Vol. 11, No. 02; 2026

ISSN: 2456-3676

A Numerical Investigation of Solar Thermal Radiation and Non-Fourier Heat Conduction in Solar Aircraft Wings Using Ternary Hybrid Nanofluids

Adediran Dauda Adeshola[1,] A. K. Jimoh[1,] Ajibade Saheed Kunle[1,] Ishola Abdulmuiz Adeshina[1,] A. M Obalalu[1],

[1]Department of Mathematics and Statistics, Kwara State University, Malete, Nigeria.

Corresponding author: adebowale.obalalu17@gmail.com

doi.org/10.51505/ijaemr.2026.11207 URL: http://dx.doi.org/10.51505/ijaemr.2026.11207

Received: Feb 25, 2026 Accepted: Mar 02, 2026 Online Published: Mar 18, 2026

Abstract

The aim of this study is to enhance the operating thermal efficiency of solar aircraft through the use of solar thermal radiation and ternary hybrid nanofluids (THNF). The study inspects the convective thermal transfer in wings of solar aircraft using a noble innovative THNF which consists of has Copper (Cu), SiO2 Silicon dioxide, Zirconium dioxide (Zr02) nanoparticles and in Propylene glycol (C3H8O2) as the basic fluid. The model used to analyze the problem uses a parabolic trough solar collector (PTSC) to model the solar thermal radiation and makes use of Cattaneo-Christov heat flux model in order to account for the non-Fourier heat conduction phenomena. Wavelets and Gegenbauer wavelets methods was uses to solve the system of ODEs. The study results display that the improvement of thermal transport via THNF is due to the advanced thermal conductivity of the nanoparticles and elevated capability of the THNF to collect and absorb solar power energy. The Cattaneo-Christov model offers a better representation of heat flux with the incorporation of thermal time delay resulting in the enhanced prediction of thermal behavior in the aircraft wings. Also, PTSC is significantly beneficial in the enhancement of the thermal management procedure of the solar energy harvesting process.

Keywords: solar aircraft, nanoparticles, Cattaneo-Christov model, Solar-powered ships, Porous Medium, Propylene glycol

1. Introduction

Realizing the impact of heat radiation in various disciplines, including industrial processes, biotechnology, pharmaceuticals, environmental applications, and so on, has advanced significantly in recent years. In physics, engineering, and other sciences, thermal radiation greatly impacts how various systems behave [1]. They also serve as the foundation for figuring out how to design and operate various applications, including biological systems, mechanical systems, equipment, and environmental phenomena, among many others. Radiation is simply energy in motion, either as electromagnetic waves or as fast-moving particles [1]. The term

Vol. 11, No. 02; 2026

ISSN: 2456-3676

"radiation" usually refers to ionizing radiation, such as beta particles and gamma rays, which have enough energy to liberate electrons in the substance they contact with. All of the things we touch, eat and breathe naturally include radioactive elements, which are chemicals that emit radiation. Cosmological radiation continuously bombards Earth's atmosphere; some of it even reaches the surface [1, 2]. Every person on the earth is exposed to radiation, a recognized carcinogen and mutagen, for every second of the day. In addition to being a necessary component of our surroundings, radiation is used extensively in scientific, industrial, and medical research. Many authors from across the world have recently looked at heat radiation in different situations. Among the significant authors are [3–7]. The impact of heat radiation on an MHD maxwellian fluid flow over an expanding surface was investigated by Aliakbar et al. [8]. The resultant ordinary differential equation was examined using the homotopy analysis approach, and the study's findings showed that the flow model's temperature increases as thermal radiation grows. Misra and Sinha [9] conducted a thorough investigation on the effects of heat radiation on MHD blood flow while taking a porous stretching sheet into account. The flow problem was analyzed using a developed numerical approach, and the outcome showed that the temperature of the MHD blood fluid rises with increasing radiation parameter. An electrically conducting magnetohydrodynamic nanofluid flow across an expanding surface was studied by Daniel et al. [10] in relation to the impact of heat radiation. Using partial differential equations to describe the flow issue, an appropriate similarity variable was used to convert the partial differential equations into ordinary differential equations, which were then solved implicitly using the finite difference method. Improved thermal radiation parameter results in higher nanofluid temperature, according to analysis.

The technological equipment known as a parabolic trough solar collector (PTSC) gathers solar radiation and transforms it into thermal energy at temperatures between 150 and 500°C on an industrial scale [11, 12]. The capacity to focus incident sunlight onto an absorber tube in the collectors' focal line is provided by the reflecting surface's cylindrical trough form and parabolic mirror section. Such PTSC typically have a width of 0.5–10 m. PTSC is mostly used in the production of solar electricity [13]. Recently, several writers from all around the world have examined PTSC in various contexts. Some of the important writers are [14–16]. Also, a numerical analysis of wind flow over a parabolic trough solar collector is conducted by Hachicha et al. [17]. Sandeep and Arunchala [18] reviewed PTSC in 2017 while taking heat augmentation methods into account. The study and manipulation of matter at dimensions roughly between 1 and 100 nm that permit special size-dependent features is known as nanotechnology, according to the US National Nanotechnology Initiative [19]. Higher-order assemblages into nanoparticles can also fall within this 1–100 nm size range, which can equate to individual molecules for polymers or other macromolecules. This size range includes tiny clusters or nanoparticles for atoms and molecules that are smaller, angstrom-sized [19]. The broader development of hybrid nanofluids has garnered significant attention in recent decades. By adding three different types of nanoparticles to the base fluid, researchers have made an incredible discovery that has led to the creation of a special nanofluid known as a ternary hybrid nanofluid [20].

Vol. 11, No. 02; 2026

ISSN: 2456-3676

There are some really intriguing features to this nanofluid. Because of their better thermophysical characteristics, ternary hybrid nanofluids have piqued the interest of many researchers [21]. In terms of their capacity to transfer heat, ternary hybrid nanofluids are far more advantageous than binary and mono nanofluids. Because of the primary characteristics of nanofluids, including their enhanced variants (ternary nanofluids), engineers and industrialists have been satiated by their extremely rich thermal mechanism. Chemical, mechanical, applied thermal, and biotechnological engineering are among the domains where these are widely applied [20]. A number of authors from throughout the globe have recently looked at ternary hybrid nanofluid in a variety of settings. Among the notable authors are [22–25]. Oladapo et al. [26] examined a comparison of ternary and tetra hybrid nonofluids that contained iron oxide, copper, zirconium dioxide, and aluminum oxide in an ethylene glycol base fluid. The flow model including variable attributes was analyzed using a time-dependent variable.

The homotopy analysis method was used to numerically analyze this work. An improvement in the thermal field was noted upon increasing the solar radiation parameter. Solar-powered aircraft are electric vehicles that run on solar energy. They can be airships, blimps, or airplanes [26]. The energy generated by the solar cells is stored in the form of hydrogen or batteries, which is then used at night when the sun doesn't shine. Solar-powered aircraft can fly for months at a time at heights of over 20 to 100 kilometers because they don't need fuel, which means they don't need oxygen [26].

Solar-powered aircraft could therefore be utilized for telecommunication, video/imagery, weather radar-based precipitation detection, flight control, geopositioning Global Positioning Systems, and other pseudo satellite applications that relay data back to ground stations. An energy plane fueled by the sun is shown in Figure 1 [27].

The aim of this study is to enhance the thermal efficiency and energy management of solar aircraft by employing solar thermal radiation and ternary hybrid nanofluids (THNF) composed of copper (Cu), silicon dioxide (SiO_2), and zirconium dioxide (ZrO_2) nanoparticles in a propylene glycol base fluid. This is achieved through the integration of the Cattaneo-Christov heat flux model and a parabolic trough solar collector (PTSC) to optimize heat transfer in the aircraft wings. Figure 1 display the innovative solar aircraft design

Vol. 11, No. 02; 2026

ISSN: 2456-3676



Figure 1a: Innovative Solar Aircraft Design

2. Flow model

The following outlines the norms and settings used to describe the movement across the horizontal surface.

- Copper (Cu), SiO_2 Silicon dioxide, Zirconium dioxide ($Zr0_2$) nanoparticles,
- Thermal radiation, second law of thermodynamics, Tiwari & Das nanofluid scheme.
- Propylene glycol, Viscous dissipation, Steady, Laminar, Slip velocity,
- Porous media, non-regular extending velocity, Cattaneo Christov heat flux.

The non-regular extending speed is defined as U_w(x, t) =bx, and surface temperature $T_w(x,0) = T_\infty + b^* x$. Where T_∞(Surrounding temperature), b(Initial extension rate), b^*(Rate of thermal variation). The ternary hybrid nanofluid was created by initially introducing Copper (Cu), (SiO_2) Silicon dioxide, Zirconium dioxide ($Zr0_2$) nanoparticles into Propylene glycol at an optimal volume fraction β_{SiO_2}, β_{Cu}, β_{Zr0_2} and kept constant at 0.09 throughout the experiment. Figure 3 illustrates the geometric representation of the flow.

Vol. 11, No. 02; 2026

ISSN: 2456-3676

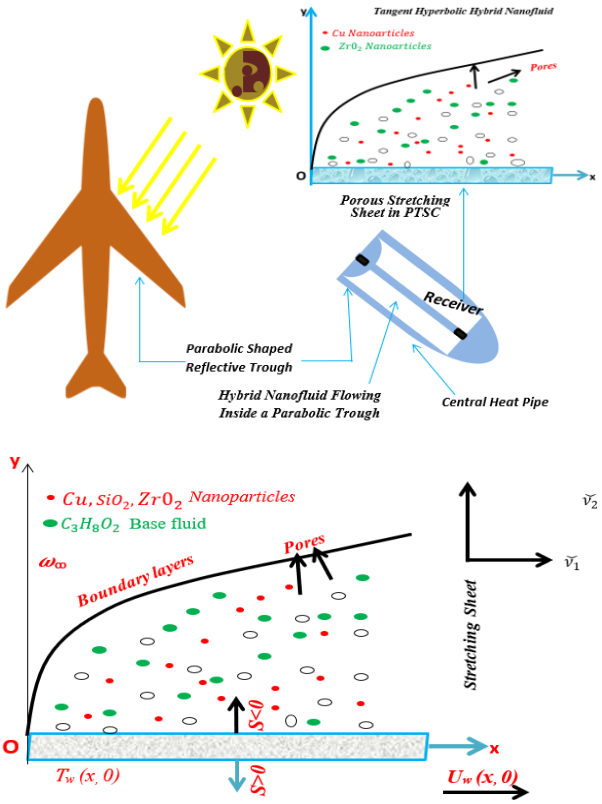


Figure 1b: The systematic diagram

The governing equations for tangent hyperbolic ternary hybrid nanofluid are:

$$\frac{\partial \breve{v}_1}{\partial x} + \frac{\partial \breve{v}_2}{\partial y} = 0, \tag{1}$$

$$\breve{v}_1 \frac{\partial \breve{v}_1}{\partial x} + \breve{v}_2 \frac{\partial \breve{v}_2}{\partial y} = \frac{\mu_{thnf}}{\rho_{thnf}} \left[(1-n) + n\sqrt{2\varsigma \left(\frac{\partial \breve{v}_2}{\partial y} \right)} \right] \frac{\partial^2 \breve{v}_1}{\partial y^2} - \frac{\mu_{thnf}}{\rho_{thnfk}} \breve{v}_1, \tag{2}$$

$$\breve{v}_1 \frac{\partial T}{\partial x} + \breve{v}_2 \frac{\partial T}{\partial y} = \tag{3}$$

$$\frac{1}{(\rho C_p)_{thnf}} \left[k_{thnf} \left(\frac{\partial^2 T}{\partial y^2} \right) - \left(\frac{\partial q_2}{\partial y} \right) + \mu_{thnf} \left(\frac{\partial \breve{v}_1}{\partial x} \right)^2 \right] - \varepsilon^* \left[\breve{v}_1 \left(\frac{\partial \breve{v}_1}{\partial x} \frac{\partial T}{\partial x} \right) + \breve{v}_2 \left(\frac{\partial \breve{v}_2}{\partial y} \frac{\partial T}{\partial y} \right) + \breve{v}_1 \left(\frac{\partial \breve{v}_2}{\partial x} \frac{\partial T}{\partial x} \right) + \breve{v}_2 \left(\frac{\partial \breve{v}_1}{\partial y} \frac{\partial T}{\partial y} \right) + \breve{v}_1^2 \left(\frac{\partial^2 T}{\partial x^2} \right) + \breve{v}_2^2 \left(\frac{\partial^2 T}{\partial x^2} \right) + 2\breve{v}_1 \breve{v}_2 \frac{\partial^2 T}{\partial x \partial y} \right]$$

,

$$E_G = \frac{k_{hnf}}{T_\infty^2} \left[1 + \frac{16\sigma^* T_\infty^3}{k^* \upsilon_f (\rho C_p)_f} \right] \left(\frac{\partial \breve{v}_1}{\partial y} \right)^2 + \frac{\mu_{hnf}}{\omega_\infty} \left(\frac{\partial \breve{v}_1}{\partial y} \right)^2 \tag{4}$$

Vol. 11, No. 02; 2026

ISSN: 2456-3676

With boundary conditions

$\breve{v_1}(x,0) = U_w + \mu_{thnf}\left(\frac{\partial \breve{v_1}}{\partial y}\right)$, $\breve{v_1}(x,0) = v_w$,

$-B_g\left(\frac{\partial T}{\partial y}\right), = P_g(T_w - T)$,

$\breve{v_1} \longrightarrow 0, \quad T \longrightarrow T_\infty, \quad \text{as} \quad y \longrightarrow \infty.$

Here, T is the Temperature of the fluid, (n) Index of the power-law, (P_g) Thermal conductivity of the solid material, (ε^*) thermal relaxation time.

3. Similarity transformations

Streaming functions are defined as this:

$\breve{v_1} = \frac{\partial \psi}{\partial y}$, and $\breve{v_2} = -\frac{\partial \psi}{\partial x}$, $\Pi(x,y) = \sqrt{\frac{b}{v_f}}y$, (2)

$\phi(\Pi) = \frac{T - T_\infty}{T_w - T_\infty}$, $\psi(x,y) = \sqrt{v_f b}\, x f(\Pi)$,

into equations (1) - (4). We obtain

$(1\text{-}n)\, f''' + f''' f'' mWe + f'' f \delta_a \delta_b - f'^2 \delta_a \delta_b - f' K = 0,$ (3)

$\left(1 + \frac{1}{\delta_d} PrNr\right)\theta'' + \frac{\delta_c}{\delta_d} Pr\, f\theta' - \frac{\delta_c}{\delta_d} Pr\, f' + \frac{PrEc}{\delta_a \delta_d} f''^2 + \frac{\phi_c}{\phi_d} Pr\, \varepsilon^* f f' \theta' + \frac{\delta_c}{\delta_d} Pr\, \varepsilon^* f^2 \theta'' = 0,$ (4)

$N_G = Re\left[\delta_d (1 - Nr)\theta'^2 \frac{1}{\delta_a} + \frac{Br}{\Omega}(f''^2 + K f'^2)\right],$

With

$f(0) = S, \theta'(0) = -B_i\big(1 - \theta(0)\big), \qquad f'(\Pi) \longrightarrow 0, f'(0) = 1 + \frac{\gamma}{\phi_a} f''(0), \theta(\Pi) \longrightarrow 0,$ (5)

as $\Pi \longrightarrow \infty$.

Physical concern parameters

Surface Drag Coefficient and heat transfer rate are defind as:

$C_f = \frac{\tau_w}{\rho_{thnf} U_w^2}$ where $\tau_w = \mu_{hnf}(1 - n)\left(\frac{\partial v_1}{\partial y}\right)_{y=0} + n\sqrt{\varsigma x}\left(\frac{\partial v_1}{\partial y}\right)^2_{y=0}$, (6)

and

Vol. 11, No. 02; 2026

ISSN: 2456-3676

$Nu_x = \frac{xq_w}{k_f(T_w - T_\infty)}, q_w = -k_{thnf}\frac{16}{3}\frac{\sigma^* T_\infty^3}{k^* v_f(\rho C_p)_f}\left(\frac{\partial T}{\partial y}\right),$

Using the nondimensional equation, we obtain:

$Re_x^{1/2} C_f = \frac{1}{\delta_a \delta_b}\left[f''(0)(1-n) + (f''(0))^2 \frac{nW_e}{2}\right]$, and $Re_x^{1/2}\, Nu_x = -\frac{k_{hnf}}{k_f}[(1 - Nr)\theta'(0)]$, (7)

Numerical solution

Application of Wavelets and Gegenbauer wavelets Method.

Wavelets and Gegenbauer wavelets methods are two of kinds mathematical methods employed in the solving of ODE, signal processing, and data compression; Wavelets are specialized in the decomposition of signals into the various frequencies that are useful in multiresolution analysis while Gegenbauer wavelets solve other intricate problems with boundary conditions and singularities involving use of orthogonal polynomials. The Flow chart of the algorithm of the present work is displayed in figure 1d.

Vol. 11, No. 02; 2026

ISSN: 2456-3676

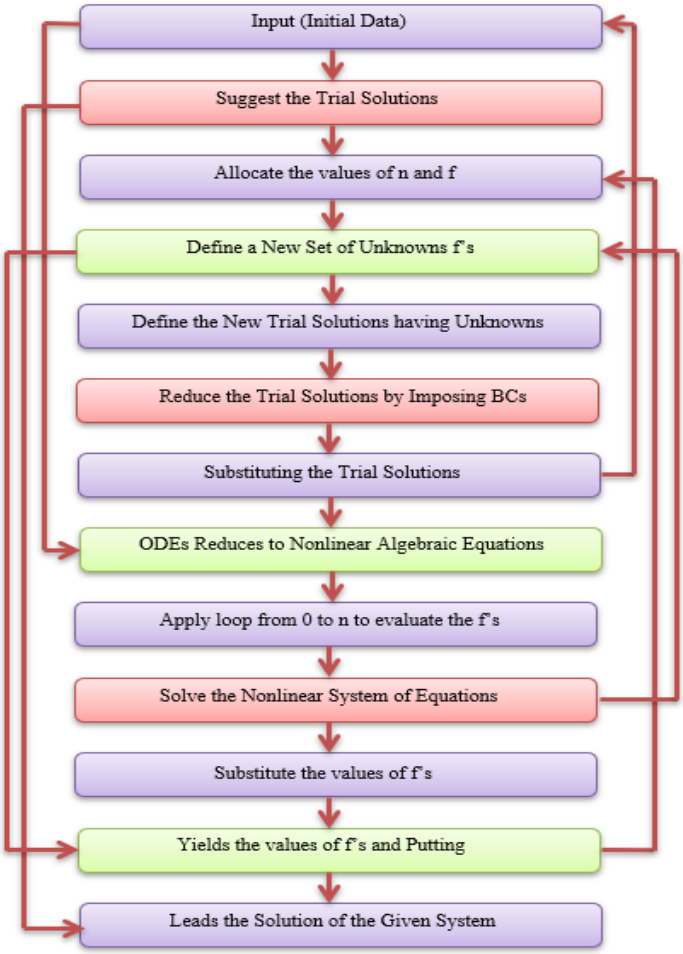


Figure 1d: Flow chart of the algorithm.

Result and conclusion

The results of this study reveal significant improvements in the thermal transfer capabilities of solar aircraft wings when employing ternary hybrid nanofluids (THNF) consisting of copper (Cu), silicon dioxide (SiO_2), and zirconium dioxide (ZrO_2) nanoparticles in a propylene glycol base. The Nusselt number (Nux) is crucial for evaluating the heat transfer rate to the core. The Nusselt number values shown in Table below confirm the anticipated result of achieving more effective heat transport with ternary hybrid nanofluids than with hybrid nanofluids, which aims to enhance heat transmission. Improving factors like Nr raises the Nusselt number at the plate wall, whereas factors such as We, and Ec lower it. In summary, THNF show better heat transfer performance than HNF.

The solar radiation parameter measures the energy received by a system from the sun. When more energy is transferred into a fluid or medium, it increases the thermal energy. As this

Vol. 11, No. 02; 2026

ISSN: 2456-3676

parameter goes up, the temperature profile rises, especially in systems that use nanofluids or in applications like solar collectors and aircraft wings (See figure 2). In nanofluid-based systems, heat transfer can be enhanced even further by solar radiation. This is because nanoparticles improve the thermal conductivity of the fluid. Together, these factors contribute to an overall increase in the temperature of the flowing fluid

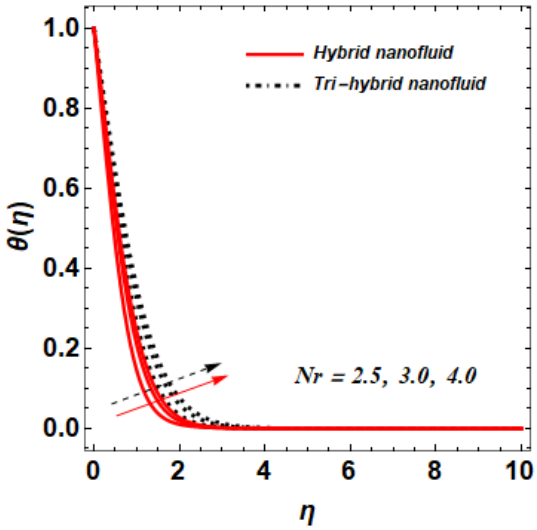


Figure 2: Effect of solar radiation parameter on temperature profile.

It has been observed that as the Reynolds number and Brinkman number increase, the generation of entropy also rises. The Reynolds number indicates the balance between inertial forces and viscous forces within a fluid. When the Reynolds number (Re) is high, the fluid flow becomes faster and more turbulent. This turbulence causes the layers of fluid to move more randomly, which increases friction between them. As this friction increases, so does the rate of irreversibility (dissipative effects), leading to higher entropy production. On the other hand, the Brinkman number relates to heat dissipation due to viscous action. It represents the ratio of heat generated by viscous effects to the heat transported through conduction in the fluid. A higher Brinkman number (Br) indicates that viscous heating is more significant compared to heat conduction. This results in additional irreversibilities and increased entropy, particularly in situations where viscous dissipation is a major factor, such as with highly viscous fluids or at high flow rates. This performance is display in Figure 3 and Figure 4.

Vol. 11, No. 02; 2026

ISSN: 2456-3676

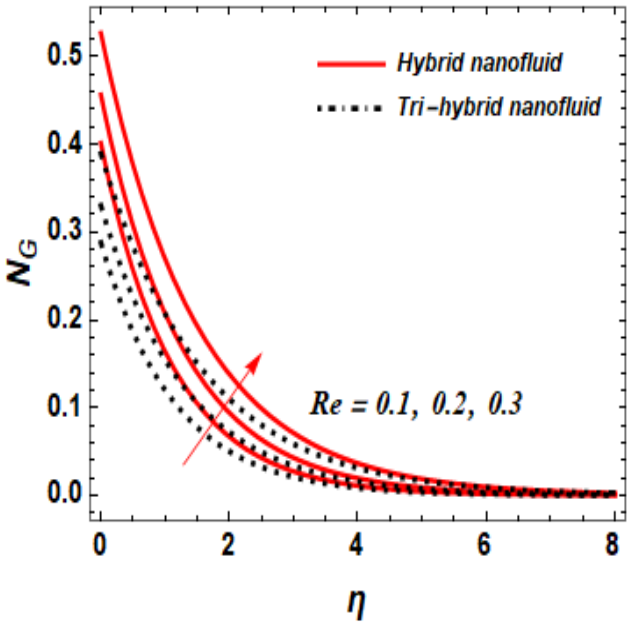


Figure 3: Effect of Reynolds number on entropy generation.

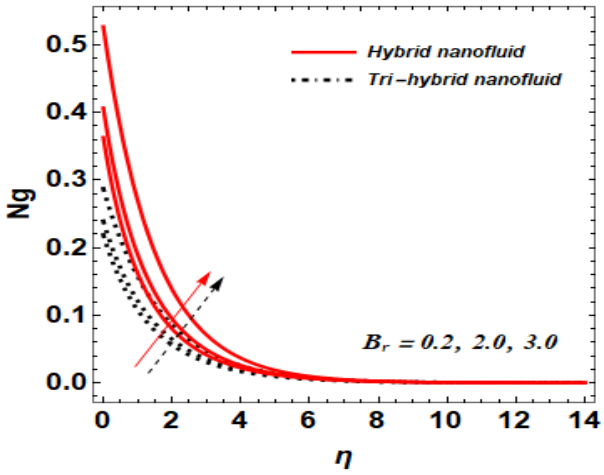


Figure 4: Effect of Brinkman number on entropy generation.

The velocity slip parameter (γ) measures how much the fluid's velocity at the wall's velocity. When γ increases, the no-slip condition becomes less strict. This means that the interaction between the fluid and the wall decreases, which reduces the shear stress at the wall. In fluid flow, a higher velocity slip parameter indicates less friction or drag force on the wall. This reduction in drag means there is less momentum exchange between the fluid and the surface. Additionally, layering effects slow down the velocity gradient near the boundary, leading to a decrease in the overall fluid flow velocity close to the surface. An increase in the velocity slip parameter (γ)

Vol. 11, No. 02; 2026

ISSN: 2456-3676

results in fewer interactions between the fluid and the wall, ultimately reducing the fluid flow rate within the boundary layer. This performance is display in Figure 5.

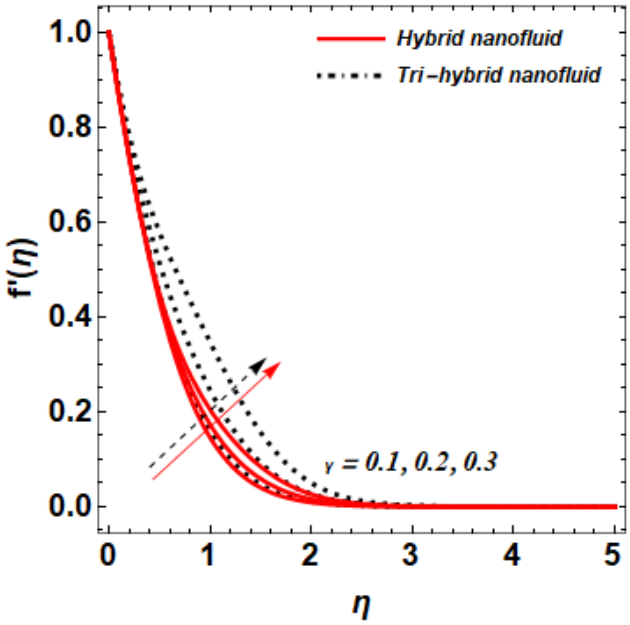


Figure 5: Effect of velocity slip parameter on fluid flow.

Suction helps stabilize the boundary layer by making it thinner. This thinning increases the velocity gradient near the surface, leading to a higher shear rate. As a result, fluid flow gets closer to the surface, which increases the velocity. On the other hand, injection creates a thicker boundary layer by adding mass to the flow, which decreases the velocity gradient. Consequently, the velocity profile fluid flow slows down, reducing the overall velocity near the surface. Suction also aids in the cooling process by drawing in cooler fluid from the edges of the boundary layer. This action thins the thermal boundary layer and causes the temperature distribution temperature profile to decrease more sharply near the surface. When considering injection (where $S < 0$ $), warmer fluid is introduced into the boundary layer. This tends to energize the thermal boundary layer, causing the temperature profile decrease at a slower rate, which results in lower heat transfer rates. In the suction scenario, the boundary layer becomes thinner, leading to a sharp rise in the velocity gradient. This increase results in higher viscous dissipation and generates more entropy due to fluid friction. For injection (again, where $S < 0$), while it aims to reduce thickness, it increases the boundary layer thickness and decreases the velocity gradient. Thus, the contribution of viscous dissipation to entropy decreases. This reorganized version presents the information in a more digestible way while maintaining the original meaning. This performance is display in Figure (6-10).

Vol. 11, No. 02; 2026

ISSN: 2456-3676

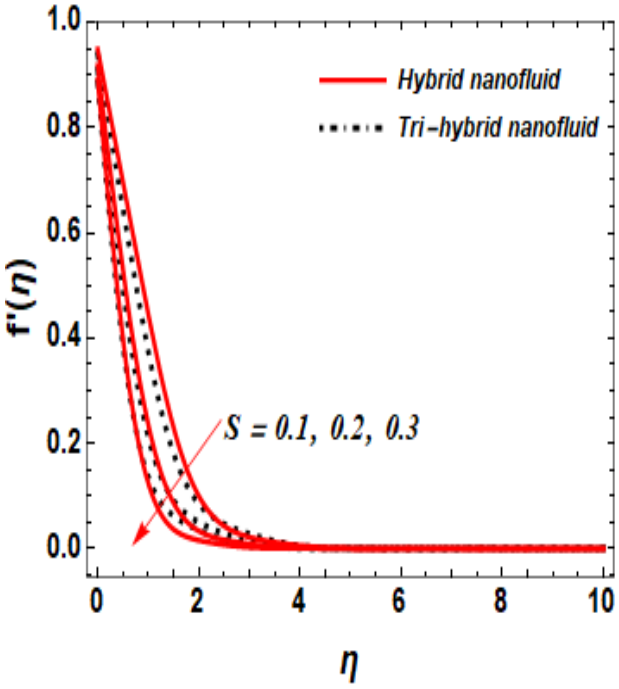


Figure 6: Effect of S parameter on fluid flow.

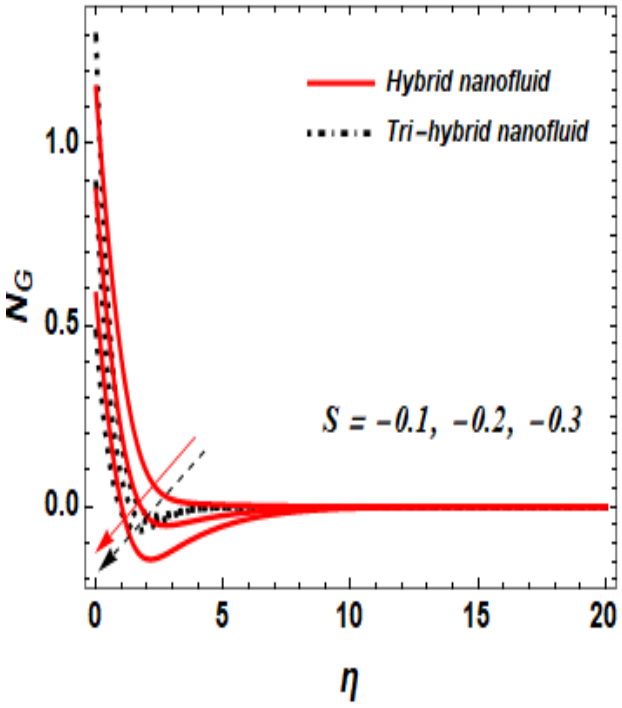


Figure 7: Effect of S parameter on entropy generation.

Vol. 11, No. 02; 2026

ISSN: 2456-3676

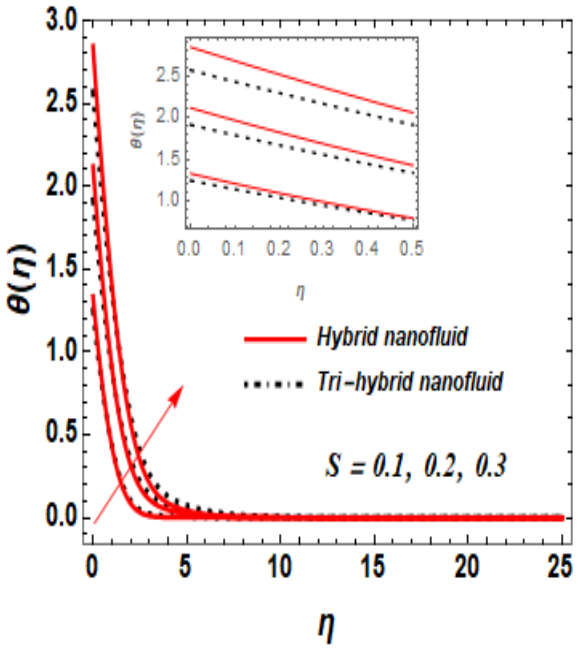


Figure 8: Effect of S parameter on temperature profile.

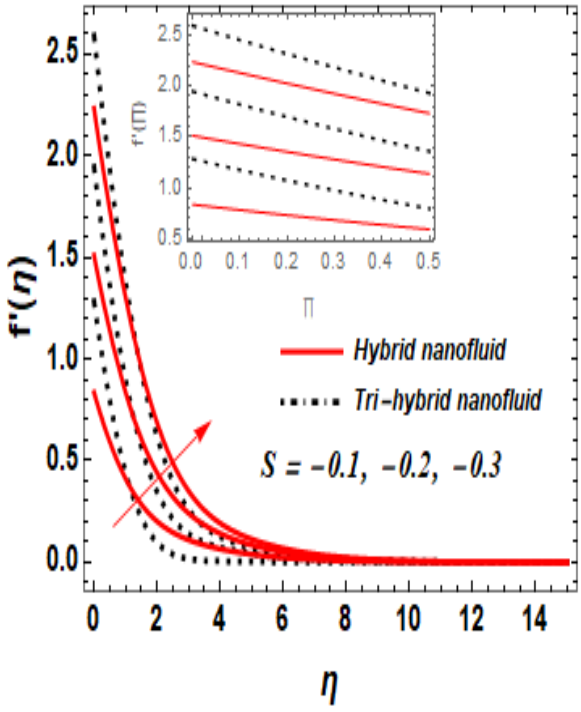


Figure 9: Effect of S parameter on fluid flow.

Vol. 11, No. 02; 2026

ISSN: 2456-3676

Conclusion

In conclusion, this study successfully demonstrates the potential of ternary hybrid nanofluids (THNF) in enhancing the thermal efficiency of solar aircraft. The combination of copper (Cu), silicon dioxide (SiO_2), and zirconium dioxide (ZrO_2) nanoparticles in a propylene glycol base fluid improves thermal conductivity and enhances the ability to capture and store solar energy. The use of the Cattaneo-Christov heat flux model effectively incorporates non-Fourier heat conduction, accounting for thermal time delay and offering a more accurate prediction of heat transfer in solar aircraft wings. Additionally, the integration of a parabolic trough solar collector (PTSC) further optimizes solar energy harvesting. Together, these innovations provide a robust solution for advancing the thermal management system in solar aircraft, contributing to improved operational efficiency. Future studies should explore other nanoparticle combinations or fluid bases to evaluate their performance and potential for further enhancing thermal conductivity and energy absorption..

References

L.-g. Kong, X.-l. Chen, J.-h. Gong, D.-j. Fan, B.-l. Wang and S. Li, "Optimization of the hybrid solar power plants comprising photovoltaic and concentrating solar power using the butterfly algorithm," Energy Conversion Management, vol. 257, pp. 115310, 2022.

M. Mathew, "Nuclear energy: A pathway towards mitigation of global warming," Progress in Nuclear Energy, vol. 143, pp. 104080, 2022.

Salawu, S. O., Obalalu, A. M., & Shamshuddin, M. D. (2023). Nonlinear solar thermal radiation efficiency and energy optimization for magnetized hybrid Prandtl–Eyring nanoliquid in aircraft. Arabian Journal for Science and engineering, 48(3), 3061-3072.

Fatunmbi, E. O., Salawu, S. O., & Obalalu, A. M. (2023). Comparative assessment of propylene glycol Molybdenum disulfide (MoS2) and silicon dioxide (SiO2) Prandtl-Eyring fluid experiencing non-uniform heat source, Navier slips and nonlinear thermal radiation. Inorganic Chemistry Communications, 111569.

Obalalu, A. M. (2021). Heat and mass transfer in an unsteady squeezed Casson fluid flow with novel thermophysical properties: Analytical and numerical solution. Heat Transfer, 50(8), 7988-8011.

Obalalu, A. M., Ajala, O. A., Abdulraheem, A., & Akindele, A. O. (2021). The influence of variable electrical conductivity on non-Darcian Casson nanofluid flow with first and second-order slip conditions. Partial Differential Equations in Applied Mathematics, 4, 100084.

Salawu, S. O., Obalalu, A. M., & Okoya, S. S. (2022). Thermal convection and solar radiation of electromagnetic actuator Cu–Al2O3/C3H8O2 and Cu–C3H8O2 hybrid nanofluids for solar collector optimization. Materials Today Communications, 33, 104763.

Salawu, S. O., Obalalu, A. M., Fatunmbi, E. O., & Shamshuddin, M. D. (2023). Elastic deformation of thermal radiative and convective hybrid SWCNT-Ag and MWCNT-MoS4 magneto-nanofluids

Vol. 11, No. 02; 2026

ISSN: 2456-3676

Obalalu, A. M., Alfwzan, W. F., Memon, M. A., Darvesh, A., Adegbite, P., Hendy, A. S., & Ali, M. R. (2024). Energy optimization of quadratic thermal convection on two-phase boundary layer flow across a moving vertical flat plate. Case Studies in Thermal Engineering, 55, 104073.

Obalalu, A. M., Alqarni, M. M., Odetunde, C., Memon, M. A., Olayemi, O. A., Shobo, A. B., ... & Hendy, A. S. (2023). Improving agricultural efficiency with solar-powered tractors and magnetohydrodynamic entropy generation in copper–silver nanofluid flow. Case Studies in Thermal Engineering, 51, 103603.

Aliakbar V, Alizadeh-Pahlavan A, Sadeghy K. The influence of thermal radiation on MHD flow of Maxwellian fluids above stretching sheets. Communications in Nonlinear Science and Numerical Simulation. 2009 Mar 1;14(3):779-94.

Misra JC, Sinha A. Effect of thermal radiation on MHD flow of blood and heat transfer in a permeable capillary in stretching motion. Heat and Mass Transfer. 2013 May; 49:617-28.

Daniel YS, Aziz ZA, Ismail Z, Salah F. Thermal radiation on unsteady electrical MHD flow of nanofluid over stretching sheet with chemical reaction. Journal of King Saud University-Science. 2019 Oct 1;31(4):804-12.

Price H, Lu¨ pfert E, Kearney D, Zarza E, Cohen G, Gee R, Mahoney R. Advances in parabolic trough solar power technology. J. Sol. Energy Eng.. 2002 May 1;124(2):109-25.

Fuqiang W, Ziming C, Jianyu T, Yuan Y, Yong S, Linhua L. Progress in concentrated solar power technology with parabolic trough collector system: A comprehensive review. Renewable and Sustainable Energy Reviews. 2017 Nov 1;79:1314-28.

Giostri A, Binotti M, Astolfi M, Silva P, Macchi E, Manzolini G. Comparison of different solar plants based on parabolic trough technology. Solar Energy. 2012 May 1;86(5):1208-21.

Shafiq A, Çolak AB, Sindhu TN. Comparative analysis to study the Darcy–Forchheimer Tangent hyperbolic flow towards cylindrical surface using artificial neural network: an application to Parabolic Trough Solar Collector. Mathematics and Computers in Simulation. 2024 Feb 1;216:213-30.

Mehta B, Subhedar D, Panchal H, Said Z, Sharma K, Siddiqui MI, Natrayan L, Rosen MA. Twisted tape inserts in parabolic trough solar collectors: Assessment of Energy, Exergy, and Environmental impacts. Applied Thermal Engineering. 2024 Aug 1;250:123566.

Elwekeel FN, Abdala AM. Numerical analysis of the heat transfer performance of the absorber tube of a parabolic trough solar collector using the swirling flow technique. Case Studies in Thermal Engineering. 2024 Aug 1;60:104801.

Hachicha AA, Rodríguez I, Castro J, Oliva A. Numerical simulation of wind flow around a parabolic trough solar collector. Applied energy. 2013 Jul 1;107:426-37.

Sandeep HM, Arunachala UC. Solar parabolic trough collectors: A review on heat transfer augmentation techniques. Renewable and Sustainable Energy Reviews. 2017 Mar 1;69:1218-31.

Leon L, Chung EJ, Rinaldi C. A brief history of nanotechnology and introduction to nanoparticles for biomedical applications. InNanoparticles for biomedical applications 2020 Jan 1 (pp. 1-4). Elsevier.

Vol. 11, No. 02; 2026

ISSN: 2456-3676

Mahmood Z, Eldin SM, Rafique K, Khan U. Numerical analysis of MHD tri-hybrid nanofluid over a nonlinear stretching/shrinking sheet with heat generation/absorption and slip conditions. Alexandria Engineering Journal. 2023 Aug 1;76:799-819.

Cao W, Animasaun IL, Yook SJ, Oladipupo VA, Ji X. Simulation of the dynamics of colloidal mixture of water with various nanoparticles at different levels of partial slip: Ternary-hybrid nanofluid. International Communications in Heat and Mass Transfer. 2022 Jun 1;135:106069.

Najafpour A, Hosseinzadeh K, Kermani JR, Ranjbar AA, Ganji DD. Numerical study on the impact of geometrical parameters and employing ternary hybrid nanofluid on the hydrothermal performance of mini-channel heat sink. Journal of Molecular Liquids. 2024 Jan 1;393:123616.

Jan A, Mushtaq M, Hussain M. Heat transfer enhancement of forced convection magnetized cross model ternary hybrid nanofluid flow over a stretching cylinder: non-similar analysis. International Journal of Heat and Fluid Flow. 2024 Apr 1;106:109302.

Krishna SG, Shanmugapriya M, Sundareswaran R, Kumar PS. MANFIS approach for predicting heat and mass transport of bio-magnetic ternary hybrid nanofluid using Cu/Al2O3/MWCNT nanoadditives. Biomass Conversion and Biorefinery. 2024 May;14(10):11175-90.

Obalalu, A. M., Oni, M. O., Khan, U., Abbas, A., Muhammad, T., & Zaib, A. (2024). Two-phase numerical simulation for the heat and mass transfer evaluation across a vertical deformable sheet with significant impact of solar radiation and heat source/sink. Arabian Journal for Science and Engineering, 49(8), 11053-11071.

Salawu, S. O., Obalalu, A. M., Fatunmbi, E. O., & Oderinu, R. A. (2022). Thermal Prandtl-Eyring hybridized MoS2-SiO2/C3H8O2 and SiO2-C3H8O2 nanofluids for effective solar energy absorber and entropy optimization: A solar water pump implementation. Journal of Molecular Liquids, 361, 119608.

Fatunmbi, E. O., Mabood, F., Salawu, S. O., Obalalu, M. A., & Sarris, I. E. (2024). Exploration of melting heat transfer and entropy generation in a magnetized hybrid nanoliquid over an extending sheet of varying thickness. Partial Differential Equations in Applied Mathematics, 11, 100835.

Olilima, J., Mogbademu, A., Memon, M. A., Obalalu, A. M., Akewe, H., & Seidu, J. (2023). An innovative inertial extra-proximal gradient algorithm for solving convex optimization problems with application to image and signal processing. Heliyon, 9(10).

Olayemi, O. A., Obalalu, A. M., Odetunde, C. B., & Ajala, O. A. (2022). Heat transfer enhancement of magnetized nanofluid flow due to a stretchable rotating disk with variable thermophysical properties effects. The European Physical Journal Plus, 137(3), 393.

Nimmy, P., Obalalu, A. M., Nagaraja, K. V., Madhukesh, J. K., Khan, U., Ishak, A., ... & Abdou, M. M. M. (2024). Thermal scrutinization of time-dependent flow of nanoparticles over a rotating sphere with autocatalytic chemical reaction. The European Physical Journal Plus, 139(3), 1-15.

Vol. 11, No. 02; 2026

ISSN: 2456-3676

Olayemi, O. A., Al-Farhany, K., Ibitoye, S. E., & Obalalu, A. M. (2022). Mixed convective heat transfer in a lid-driven concentric trapezoidal enclosure: numerical simulation. International Journal of Engineering Research in Africa, 60, 43-62.

M. Sippel, D. Meyer and N. Scholliers, "What about greenhouse gas emissions from students? An analysis of lifestyle and carbon footprints at the University of Applied Science in Konstanz, Germany," Carbon Management, vol. 9, no. 2, pp. 201-211, 2018.

Gasmi, H., Obalalu, A. M., Akindele, A. O., Salaudeen, S. A., Khan, U., Ishak, A., ... & Abed, A. M. (2024). Thermal performance of a motile-microorganism within the two-phase nanofluid flow for the distinct non-Newtonian models on static and moving surfaces. Case Studies in Thermal Engineering, 58, 104392.

Olayemi, O. A., Al-Farhany, K., Obalalu, A. M., Ajide, T. F., & Adebayo, K. R. (2022). Magnetoconvection around an elliptic cylinder placed in a lid-driven square enclosure subjected to internal heat generation or absorption. Heat Transfer, 51(6), 4950-4976.

Mahboobtosi M, Hosseinzadeh K, Ganji DD. Investigating the convective flow of ternary hybrid nanofluids and single nanofluids around a stretched cylinder: Parameter analysis and performance enhancement. International Journal of Thermofluids. 2024 Aug 1;23:100752.

Safyanu BD, Abdullah MN, Omar Z. Review of power device for solar-powered aircraft applications. Journal of Aerospace Technology and Management. 2019 Oct 10;11:e4119.

Abbe G, Smith H. Technological development trends in Solar-powered Aircraft Systems. Renewable and Sustainable Energy Reviews. 2016 Jul 1;60:770-83.

Allehiany, F. M., Shaikh, G. M., Memon, A. A., Memon, M. A., & Obalalu, A. M. (2024). Investigating the Effect of Cu-Al2O3 Hybrid Nanofluids on the Electrical Performance of PV/T Systems with Backward Step Flow Channel. Journal of Applied and Computational Mechanics.

Nimmy, P., Obalalu, A. M., Nagaraja, K. V., Madhukesh, J. K., Khan, U., Ishak, A., ... & Abed, A. M. (2024). Computational analysis of nanoparticles and waste discharge concentration past a rotating sphere with Lorentz forces. Applied Rheology, 34(1), 20240012.

H. K. Gupta, G. D. Agrawal and J. J. C. S. i. T. E. Mathur, "Investigations for effect of Al2O3–H2O nanofluid flow rate on the efficiency of direct absorption solar collector," Case Studies in Thermal Engineering, vol. 5, pp. 70-78, 2015.

Z. Yang, A magnetorheological study of single-walled and multi-walled carbon nanotube dispersions in mineral oil and epoxy resin, University of North Texas, 2005.

S. Musić and M. Ristic, "Adsorption of zinc (II) on hydrous iron oxides," Journal of radioanalytical nuclear chemistry, vol. 162, no. 2, pp. 351-362, 1992.

S. Das, N. Mahato, A. Ali and R. Jana, "Dynamical behaviour of magneto-copper-titania/water-ethylene glycol stream inside a gyrating channel," Chemical Physics Letters, vol. 793, pp. 139476, 2022.