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Review of the conical pin fin heat sink

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ABSTRACT

In industrial and electronic applications, the research on enhancing the performance of heat sinks is of increasing importance. The objective is to reduce weight and costs while simultaneously improving thermal and hydraulic efficiency. This study provides a thorough examination of theoretical, numerical, and experimental research that pertains to the optimization and design of heat sinks with a variety of geometric shapes. We theoretically derived analytical equations for one-dimensional conductive heat transfer, which facilitated the determination of the optimal dimensions of fins of various types, including rectangular, triangular, vertical, and circular fins, as well as fins with conical, concave, and convex shapes. These theoretical findings established a scientific foundation for the development of fins that optimize thermal efficiency, minimize material consumption and weight, and consider the impact of physical and thermal properties on performance. By simulating heat transfer and fluid flow using sophisticated tools, we designed numerical studies to enhance the performance of heat sinks. These studies evaluated the impact of multiple design factors, such as fin dimensions, number, arrangement, angles of inclination, and different geometric shapes, under a variety of flow conditions. The objective of these studies was to enhance the heat transfer rate and minimize thermal waste, all while creating innovative designs that can operate efficiently under a variety of operating conditions, including natural and forced cooling systems.

Introduction

Engineers design a heat sink to effectively absorb or dissipate heat using extended surfaces like fins and spines. Heat sinks find their use in numerous applications that require the efficient dissipation of thermal energy. The most prevalent of these applications are refrigeration, heat engines, and electronic device cooling[1]. A set of fins, which is a collective term for a metal structure that is outfitted with a number of cooling fins, is the typical design of a heat sink. The optimization of the heat sink's performance is contingent upon a variety of factors, such as the physical composition of the fins, the type of cooling medium, its flow rate, and the cooling mode (convection or forced convection). Vertical fins are available in cylindrical, concave, or convex configurations, while longitudinal fins can be classified as rectangular, triangular, or vertical, as shown in Fig.(1) [2].

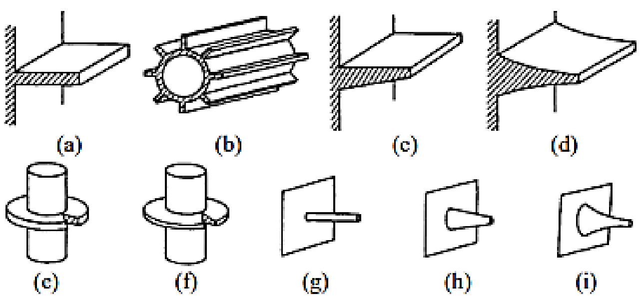

Fig (1) Some types of typical extended surfaces: (a)-(d) longitudinal slots for rectangular profiles, single, trapezoidal, and parabolic tubes; (e), (f) radial slots for rectangular and trapezoidal profiles; (g)-(i) slots for cylindrical and conical cut-off frames and parabolic cut-off , Air jet impingement, particularly with the use of multiple jets combined with surface enhancements, offers a compelling alternative, as it can achieve heat removal levels comparable to liquid cooling [3].

With this development, new challenges have emerged, the most prominent of which is the high temperature that may cause damage to electronic components. Experts face the challenge of finding cooling solutions within a limited space, with phase-change cooling emerging as a promising option [4]. Conventional heat radiators are usually based on a variety of fin surface designs, such as plate fins, cross fins, and microchannels, as well as heat radiators. Figure (2) shows a heat transfer Tester that includes components such as a flow valve, a flow meter, and a heat source to measure system performance. A cooler is used to absorb heat from the liquid, while fans cool it and devices such as a measuring device help collect and analyze data., as shown in Fig.(2) [5].

The author presented an experimental study on the heat dissipation of engineering systems during their operation. The study examined the methods for dissipating the heat generated by engineering systems during operation, as it caused the systems' temperature to rise. Therefore, the establishment of a technology to cool electronic devices should align with the required cooling capacity, Pin Fin Sample as shown fig (3).

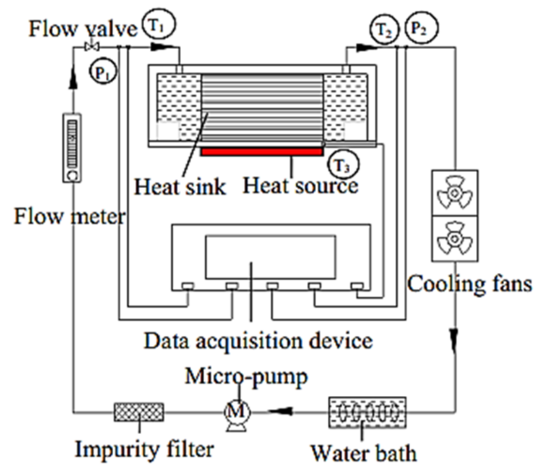

Fig (2) Diagrammatic sketch of experimental platform Gunjal et al [6].

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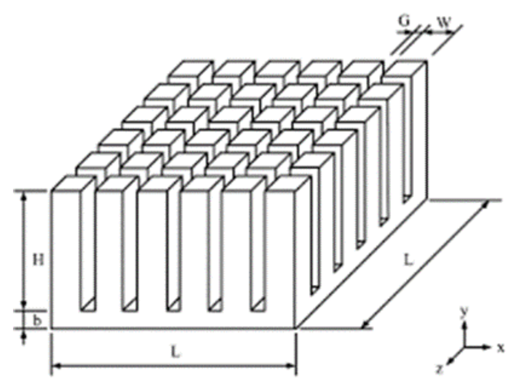


Fig (3) Pin Fin Sample[6]

Shah [7].conduct study examines the rate of heat transfer in the heat exchanger and how to increase its transfer through the use of different types of fins and find out which is better for heat transfer, especially pin fins, where the study found that it is possible to transfer heat better in the heat exchanger using straight pin fins and perforated or serrated arrangements. Khan et al[8].He presented the study of thermodynamic losses resulting from heat transfer and pressure drop of a liquid in a cylindrical thermal Basin and flow zones where the speed used depends on the Reynolds number and the pressure drop to the minimum of the liquid flow . Khan et al[9] . They presented a study on the analysis of the performance of pin fin cylindrical heat sink, as the thermal performance of pin fin heat sink depends on the dimensions of the pin fins, the density of the pins, the location and volume of heat and found that the thermal resistance decreases while the pressure lowering increases. Pakrouh et al[10]. They presented a study on the thermal performance characteristics of aluminum pin fin heatsinks, as they were chosen for their high thermal conductivity, where previous experimental studies were compared with current results and the results show that increasing the number, thickness and height of the fin leads to a significant decrease in temperature.

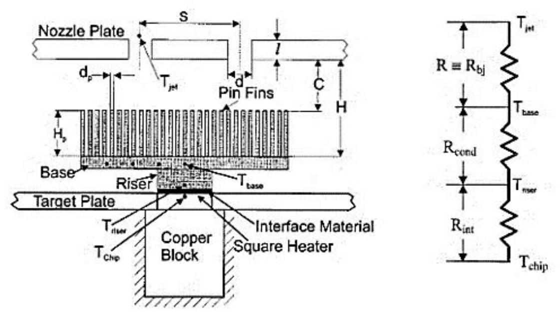
1.The Methodology

This study is based on previous reviews of the heat sink on various shapes of fins, including conical, so the article was divided as follows: fins with conical, oval and round shapes are explained in the third section, and fins with rectangular, triangular and square shapes are explained in the fourth section, mathematical equations are explained in the fifth section, results and recommendations are explained in the sixth section.

2. Fins of Conical, Oval and Round Shape

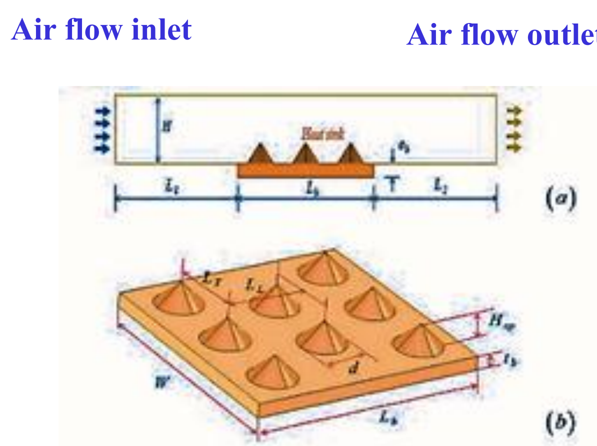
This section reviews several articles on fins with oval, conical, and circular shapes, such as Sheikh et al [11]. We conducted experimental research to improve the transfer of heat from a distinct heat source. The investigation involved a jet collision. Furthermore, we equipped a heat source with numerous pin-fin heat absorbers. We compared the results to solitary jets with the same hole diameter and area. The study obtained the highest value of the nozzle in the range of 3 to 6(a) for the mounted heat sink, which displays geometric parameters. (b) The thermal resistance diagram can be found in Fig. (4).

Souida et al [12]. He conducted a numerical study to investigate the impact of pin fin shape on the overall performance of heatsinks. The study involved the use of conical pin fins with varying cone size ratios (Hcp/d). The results indicate that there are five geometric states: Hcp/d = 0.167, 0.333, 0.500, 0.667, and 0.833. The cylindrical fins outperformed the cone-shaped fins by 343.32%, 275.92%, 205.79%, 144.86%, and 100.38% for Hcp/d = 0.167, 0.333, 0.500, 0.667, and 0.833, respectively. The coefficient of hydrothermal efficacy (h) of conical fins is higher than that of cylindrical fins ; show two designs of a finned heat exchanger. Image (A) shows a system with straight fins arranged along the surface to improve heat transfer, while image (B) shows a design with several conical fins to improve thermal performance by increasing the surface area.



(a) (b)

Fig (4) The experimental information: (a) the mounted heat sink, which displays geometric parameters. (b) a thermal resistance diagram.



Fig(5) a) Channel and b) Pin fins thermal configurations

Qin et al [13] . A numerical study examined the heat sink's heat transmission performance at temperatures of 308 K, 323 K, 338 K, 353 K, and 368 K, utilizing parametric differences in the number and height of the pin fins. Furthermore, the study examined the impact of porous ranges from 0.524 to 0.960 on thermal resistance. The study found that as the temperature difference between the heat sink and the ocean increases, the heat transmission coefficient also increases. Mohamed H.A. Elnaggar[14]. He presented an analytical study that examined the impact of the number of fins and their thickness on the performance of increasing the heat transfer rate. The study found that the number of fins has a significantly greater effect on the heat transfer rate than the thickness of the fins. However, the distance between the fins decreases as the fins' thickness increases.

Kumar et al [15].presented a study of Computational Fluid Dynamics analysis on the performance of various pin-fin heat sinks in forced convection flow where the overall performance of the heat sink is designed, geometric variables are analyzed and the results were compared through the Computational Fluid Dynamics (CFD) STARCCM program and there was agreement with the theoretical results Bailin et al[16]. presented a numerical study on the change rule by calculating the thermal resistance of the aluminum plate, the thermal resistance of convective heat transfer, and the thermal resistance of the coolant, where the simulation was carried out using the MATLAB program and the study found that the thermal resistance of convective heat transfer has a clear effect on the efficiency in terms of a certain amount of heat. Oyewole et al[17]. presented a numerical and analytical analysis of the dissipation of excess and unwanted battery temperatures by connecting a geometrically shaped heat sink (pin Fins) under the influence of air flow velocities and varying temperatures at a discharge rate of 2 degrees Celsius for three cases. The results of the study suggest that case 2—which is characterized by a uniform height—is superior to the other cases. We determined that this heatsink performs better after 600 seconds and a constant inlet air velocity of 0.412 m/s over a temperature range of 20 degrees Celsius to 35 degrees Celsius, resulting in an average improvement of 1.87% and 1.93% in temperature homogenization and maximum battery temperature, respectively. Straight Shahu et al[18]. presented an analytical study on the development of an experimental model of pin fin heatsinks for forced convection, where the heat sinks were made of aluminum and consisted of a set of overlapping pin fins, where the fin height reached 60 mm, the pin diameter was 6 mm, and the longitudinal slope was 10 mm. Zhao et al[19] . They conducted a study on the geometric features of the pin fin and the numerical results obtained a clear effect of the geometric features on the flow and heat transfer properties, where ideal porosity values were obtained in a specific acceleration of pin fins. Al Doori[20] . He presented a study on the convective heat transfer of perforated pin fins.
The objective of the investigation is to determine whe ther perforated pin fins facilitate heat transmission.
We can determine the diameter and number of holes for each pin, and we found that the Nusselt number of perforated pins was 47% greater than that of solid pins. The Nusselt number increases
as the number of holes increases. Saghi et al[21] . They presented a study on the best design for removing heat from small surfaces, where cylindrical pin fins were used by using the specified elements, Reynolds and height of pin fins were verified using the Darcy model with the effective energy equation, and the best result was obtained for the performance of 8 mm porous pin fins.Sahiti et al[22]. They presented a study of improvements in the work of cylindrical pins on the surfaces of heat exchangers, where a theoretical treatment of the method used was presented, where relations of convective and conductive heat transfer were used to derive an equation showing the achievement of improvements in heat transfer, where the proposed method proved more effective for heat transfer .Mousa et al[23]. He presented a study on heat transfer in hollow and solid pin fins using the ANSYS 16.0 program. Where it was concluded that the heat sink with solid fins is higher than hollow, where it was investigated that the perforated fin set is better and gives the best performance in terms of weight compared to other samples. Vinay Pal [24]. It was noted that the thermal mass and the geometric position of the fin play a fundamental role in determining the performance of the fin, as the heat sink depends on the function of the material, the structure of the fin and the temperature of the surrounding liquid. Younghwan Joo et al[25]. They presented a comparison on the thermal performance of the improved plate and pin fins, where a comparison was made under the same conditions and dimensions of the fin, the horizontal and vertical spacing of a group of pin fins was improved by comparing the heat exchangers of the plate pin fins, and the results showed that the heat exchangers of the plate fins are better than the pin fins.

The reviewed studies provide experimental and numerical analyzes on Pin fin heat radiators, showing significant differences in methodologies and results. Experimental studies, such as those by [11],[17], focus on realistic settings to evaluate the heat transfer performance of various fin shapes and configurations, offering practical insights on temperature changes and heat resistance. In contrast, numerical studies, such as those by [12,13] , use simulations to explore the effect of geometric coefficients and temperature changes on heat transfer efficiency. While experimental studies validate physical models, numerical studies enable a more accurate and comprehensive exploration of the parameters, offering complementary insights to improve the performance of heat radiators.

3.Fins Of Rectangular, Triangular And Square Shape

This section deals with a review of a group of articles related to fins with rectangular, square, and triangular shapes, and the review includes the following articles : Shahdad et al[26] . conduct An analytical study in the field of flow and heat transfer by turbulent flow around a set of simple and perforated fins using the Fluent program within the range of 20,000-50,000 Reynolds, using air as a working fluid with consistent physical properties, the researcher concluded that attaching some screws to ordinary fins along the passing flow would reduce the pressure. Shahid et al [27] . He presented a study on the convective heat transmission of perforate pin fins. The purpose of the study is to determine whether perf orated pin fins facilitate heat transmission. We can determine the diameter and number of holes for each pin, and we found that the noslet number of perforated pins was 47% higher than that of solid pins. The noslet number increases as the number of holes i ncreases. Li et al[28]. presented a numerical study looking at the recent developments of heat sinks over a period of five years with a major review of the aspects of heat transfer, i.e., conduction, convection and radiation. the aim of this study is to provide an overview of the current studies that raise the thermal performance of heat sinks Khan et al[29]. They presented a study on the side and Top effect on the hydraulic and thermal performance of a pin-fin cylindrical heat sink in forced convection where the experimental correlation was used to determine the friction factors and heat transfer factors and the thermal diffusion effects were neglected . Jehhef [30] . An investigation was made on the geometry of the fins with a cross-section on the thermal performance of the fins by adding a fin to the original fins, including rectangular and triangular fins, the equations of conservation of mass and energy were applied, fourteen different geometric shapes were examined and obtained as a result that the Nusselt number increases with Reynolds increase in all models that used Lakshmi Prasad K et al[31]. The Reynolds effect on the heat transfer rate was studied and it was noted that when the Reynolds increases the heat transfer rate increases and the denser design produces the highest heat transfer rate. Keshari [32] . He presented a proposed numerical study of six heat exchangers and compared between them the use of COMSOL Multiphysics 4.3 b for the design and simulation of models. Where he chose the final design based on the minimum charging time of the storage device and focused on the length of the axial distance of the storage device It was found that the middle part of the device has a constant temperature and a good choice of heat exchanger geometry is important for rapid heat absorption. Nunes et al[33].They presented a study on the effects of square fin height and the effect of pressure drop on heat transfer the HFE-7100 was used as a liquid the flow was analyzed digitally using the ANSYS FLUENT CFD program the pressure drops significantly with the steam flow without taking into account the fin height and this leads to deterioration of heat transfer . Karande et al[34] . They studied the latest developments in the design of fins in terms of geometric shapes and dimensions, as well as heat transfer and pressure drop in various operating conditions in order to improve heat transfer in the fins. Tingfang Yu et al[35]. They conducted a numerical study in the heat transfer of liquids for wavy microchannels with different fin shapes and the cooling properties were compared with the liquid for wavy and straight channels regarding pressure drop and Nusselt number, where the results proved that the wavy channels and fin shape has a significant effect on the work of the heat sink but affects the pressure drop . Khalaf et al[36]. They studied the natural convection of horizontal, vertical and inclined heat sinks in terms of heat transfer by radiation the experiments were carried out through a power between 60 watts to 455 Watts in order to obtain different heat transfer temperatures and the results showed that when the heat input increases, the heat transfer rate increases according to the comparison of the three cases, the heat transfer was improved by 6% when the temperature is 30 degrees Celsius. Yaseen et al[37]. A numerical study was conducted on a three-dimensional fluid for heat transfer in the heat sink and air was used for cooling, the thickness of the fins and their number were confirmed and a program was used Ansys Icepak to ensure the best thermal performance, the study concluded that the maximum temperature decreases with increasing the number of fins and their thickness, and the best heat transfer when the fin thickness is 15 and 0.25 mm. Fayyaz et al[38]. They conducted a numerical and experimental study of a group of triangular and square pin fins using a three-dimensional digital simulation to find out the characteristics of heat transfer, and the study concluded that the performance of the square pin fin is better in heat transfer than the triangular fin. Sharath D et al [39].Research was conducted on various geometric shapes and the heat transfer coefficient of different fins was compared by reducing the pressure, air velocity and thermal resistance of the fin .analytical calculations were made by the cfd program and the study concluded that the higher the fin height, the less pressure and the more heat transfer. Terekh et al[40]. They presented an experimental study of the heat transfer of small-sized plate-finned heatsinks designed for electronic cooling in forced convection and it was found that the spacing of the fins from 3 to 6 mm and an angle of 29 degrees leads to an increase in heat transfer of about 32% , as the new designs of heatsinks led to a heat reduction of almost 16 degrees.

Experimental studies such as those by [26] and [37] and Yasin focus on heat transfer applications in real-world systems, providing practical data on temperature reduction and pressure degradation.

In contrast, numerical studies such as the Lee and Nunes study use advanced simulation tools such as Fluent and COMSOL to study heat transfer and fluid dynamics in theoretical models.

Empirical studies provide practical verification, while numerical studies provide greater flexibility in exploring and improving designs.

4.Mathematical Equations Table (1) shows the mathematical formulas for determining the ideal dimensions for longitudinal fin configurations, Table (2) shows the mathematical formulas for determining the ideal dimensions for spinal fin configurations[41].

Table (1) Mathematical formulas for determining optimal dimensions of Longitudinal fins configurations

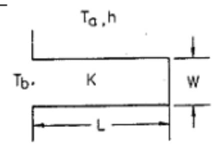
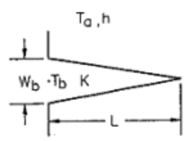
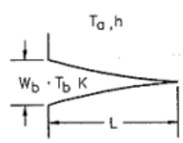
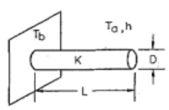
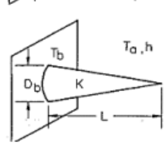
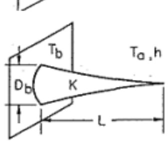
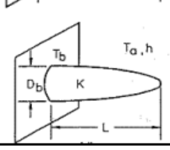
Fin geometry	Optimal dimension based on profile area L_{opt}	W_{opt}	Optimal dimension based on heat dissipation L_{opt}	W_{opt}
	$1.0023\left(\frac{A_p k}{h}\right)^{1/3}$ (10)	$0.9977\left(\frac{A_p^2 h}{k}\right)^{1/3}$ (11)	$0.7978\frac{q}{h(T_a - T_a)}$ (12)	$\frac{0.6321}{hk}\left(\frac{q}{T_b - T_a}\right)^2$ (13)
	$1.1969\left(\frac{A_p k}{h}\right)^{1/3}$ (14)	$1.6710\left(\frac{A_p^2 h}{k}\right)^{1/3}$ (15)	$0.8422\frac{q}{h(T_a - T_a)}$ (16)	$\frac{0.8273}{hk}\left(\frac{q}{T_b - T_a}\right)^2$ (17)
	$1.4422\left(\frac{A_p k}{h}\right)^{1/3}$ (18)	$2.081\left(\frac{A_p^2 h}{k}\right)^{1/3}$ (19)	$\frac{q}{h(T_a - T_a)}$ (20)	$\frac{q^2}{hk(T_b - T_a)^2}$ (21)

Table (2) Mathematical formulas for determining optimal dimensions of Spine fin configuration

Fin geometry	Optimal dimension based on volume L_{opt}	$D_{b,opt}$	Optimal dimension based on heat dissipation L_{opt}	$D_{b,opt}$
	$0.5636\left(\frac{Vk^2}{h^2}\right)^{1/5}$ (22)	$1.5031\left(\frac{V^2h}{k}\right)^{1/5}$ (23)	$0.44\left[\frac{qk}{h^2(T_a - T_a)}\right]^{1/3}$ (24)	$0.9165\left[\frac{q^2}{hk(T_b - T_a)^2}\right]^{1/3}$ (25)
	$1.0008\left(\frac{Vk^2}{h^2}\right)^{1/5}$ (26)	$1.9536\left(\frac{V^2h}{k}\right)^{1/5}$ (27)	$0.7505\left[\frac{qk}{h^2(T_a - T_a)}\right]^{1/3}$ (28)	$0.1.0988\left[\frac{q^2}{hk(T_b - T_a)^2}\right]^{\frac{1}{3}}$ (29)
	$1.4481\left(\frac{Vk^2}{h^2}\right)^{1/5}$ (30)	$2.0968\left(\frac{V^2h}{k}\right)^{1/5}$ (31)	$1.0838\left[\frac{qk}{h^2(T_a - T_a)}\right]^{1/3}$ (32)	$1.1746\left[\frac{q^2}{hk(T_b - T_a)^2}\right]^{\frac{1}{3}}$ (33)
	$0.7877\left(\frac{Vk^2}{h^2}\right)^{1/5}$ (34)	$1.7980\left(\frac{V^2h}{k}\right)^{1/5}$ (35)	$0.5951\left[\frac{qk}{h^2(T_a - T_a)}\right]^{1/3}$ (36)	$1.0262\left[\frac{q^2}{hk(T_b - T_a)^2}\right]^{\frac{1}{3}}$ (37)

4. Results And Recommendations

1. stepwise Organization of spines increases heat transfer: stepwise Organization of spines, whether round, flat, perforated or slotted, significantly enhances the heat transfer coefficient compared to parallel organization, due to increased turbulence in the flow.

2-the effect of the distance between the Thorns: increasing the distance between the Thorns improves the thermal performance of the refrigerant, as it allows better heat exchange between the liquid and the Thorns.

3. influence of the direction of the thorns and their angle of inclination: the direction of the thorns and their angle of inclination greatly affect the heat dissipation efficiency of the radiator.

4. the effect of increasing the liquid flow rate: increasing the liquid flow promotes heat transfer but may cause noise, vibrations, pressure drop, and corrosion of the Thorns.

5. improve the liquid flow in precision applications: in precision applications, the liquid flow rate should be improved to avoid pressure increase or adverse effects such as noise and vibration.

6-hybrid designs to improve thermal efficiency: it is advisable to use hybrid designs such as perforated or multi-layer thorns, but their effects on energy consumption and pressure must be taken into account.

7 - design chillers for lightweight applications: in applications that require light weight such as mobile devices, emphasis should be placed on optimizing needle spines compared to plates to achieve the best thermal performance per unit weight.

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