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Design of a Computational Tool in Matlab® for Analysis on Extended Surfaces

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Abstract

Educational Software in engineering has become a key factor to complete the program educational objectives and reach the student outcomes. This article presents the development of a computational tool developed in Matlab® that allows the determination of temperature profiles, heat transfer rate, and efficiency of eight different types of finned surfaces. Three case studies were performed, Influence of thermal conductivity on temperature profile, Analysis of the effect of heat transfer coefficient and thermal conductivity on the total heat, effectiveness and optimum length of the fin, and Fin efficiency analysis. It was found that the heat transfer rate increases as thermal conductivity increases and the temperature profile along the fin decline as heat is dissipated along it. An increase in the convective coefficient increases the heat transfer rate through the fin, causing a decline in effectiveness. The geometrical configurations of pin fin had the best heat loss due to their shapes. The software was very well accepted by 60 students and evaluated in terms of clarity, precision and relevance with a *t* test with a significance level of 5%.

Keywords: Computational Tool, Extended Surfaced, Heat Transfer, Software

1. Introduction

The use of extended surfaces, commonly called fins, are widely used devices that increase the area of heat transfer between a solid and the surrounding fluid at low cost of production [1]. Industrial processes, computer systems, refrigerators among other things, involve the generation of heat which must be removed to ensure all the systems working at its recommended temperatures. There are technical parameters such as the space and number of fins that an engineer should determine carefully in detail considering that an excessive number of fins can cause a resistance to the air flow generating a troublesome pressure drop [1-3]. In addition, a selection of adequate fins requires knowledge of temperature distributions through them, which will depend on the properties of the fin material [4]. In recent years, lots of research has been done about fin applications in specific engineering problems for example, Chen et al. [5] who studied finned condensers in the presence of the shear force at the liquid-vapor interface, Pashah et al. [6] studied the numerical solutions using psychrometric relationships for wet operating conditions in hyperbolic annular fins, Cordoba and Fuentes [7] developed a computational tool for the simulation of flow behavior in the fin-and-tube heat exchangers with phase change in the coolant side, and Zhang et al. [8], studied the heat transfer features in the fin and tube intercooler using simulation and experimental research.
Considering that the technology improved in the last decade, affecting the design of new extended surface heat exchangers, it surges the need to prepare young engineers in the understanding, designing and optimizing this kind of equipments. This advance in technology rise the need to develop new computational tools for young engineers and students so that they deeply understand the heat transfer phenomenon inside plate fin heat exchangers. Therefore, this paper presents the development of a user-friendly software in an environment of Matlab that allows the analysis of heat transfer for 8 different fins, highly interoperable, and also used as a teaching tool in a heat transfer class. Three case studies will be exposed to show the importance of the software execution, the influence of thermal conductivity on temperature profile, the analysis of the effect of heat transfer coefficient and thermal conductivity on the total heat, effectiveness and optimum length of the fin, and the fin efficiency analysis. Finally, a statistical analysis was made to a population of 60 students (two different groups of 30 students) which shows a great positive effect of the software in the class of heat transfer of mechanical engineering students.

2. Presentation

In this section, the fundamental equations used to calculate the main parameters of the fins are presented. The aim and the technical details of the engineering software education called *ProfileFins* are shown, as a support tool to enhance the skills and knowledge of the Chemical and Mechanical Engineering students according to Accreditation Board for Engineering and Technology (ABET).

2.1. Fundamental Equations

The differential equation that describe the temperature distribution along a straight triangular fin is given by equation (1)

$$\frac{d}{dx}\left[A(x)\frac{dT}{dx}\right]-\frac{hc}{k}\left[T_a-T_b\right]\frac{da(x)}{dx}=0, \quad (1)$$

With a corresponding solution given by equation (2)

$$(T-T_\infty).=C_1 l_0(mx^{0.5})+C_2 k_0(mx^{0.5}), \quad (2)$$

With a dimensionless temperature profile given by equation (3)

$$\frac{(T-T_\infty)}{(T_s-T_\infty)}=\frac{l_0(mx^{0.5})}{l_0(mL^{0.5})}. \quad (3)$$

The total heat transferred from the fin is given by equation (4)

$$Q_t=2hczLL(T_s-T_\infty), \quad (4)$$

while the fin efficiency is expressed according to equation (5)

$$\eta=\frac{(2hck)^{0.5}l_1(mL^{0.5})}{2hcLL\,l_0(mL^{0.5})} \quad (5)$$

Finally, fin effectiveness and optimum length is determined by equation (6) and (7) respectively

$$\varepsilon_{Triangular\ fin}=\frac{Q_t}{hWT(T_b-T_a)} \quad (6)$$

$$L_{optima}=0.318\sqrt{\frac{kb}{hc}} \quad (7)$$

2.2 Software Presentation

The software *ProfileFins* is a computational tool developed in Matlab that can be used by undergraduate engineering students to design plate fin heat exchangers, to take decisions related to the design of fins in view of the costs of material, and to support studies of heat transfer processes in fins. The software was developed applying a metric of quality in software development, which guarantee that the final product have characteristic such as: interoperability, reliability, facility of use, and portability that offers a friendly and entertained environment for the user.
Figure **1** show images of different work spaces of the *ProfileFin* software.

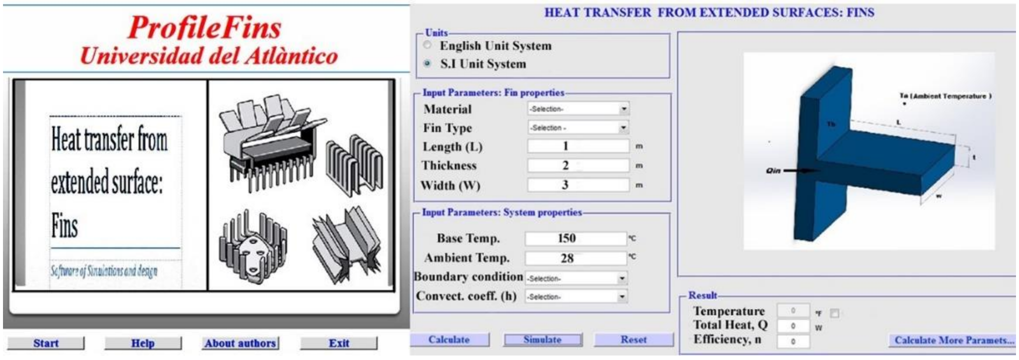

Figure 1. Main View of the *ProfileFins* Software

ProfileFins was developed with Matlab®7.0, and work with any modern version of Matlab/Simulink in Microsoft 32/64 bit Windows PC on which Matlab/Simulink is installed. All *ProfileFins* file use less than 11.6 MB disk space.

3. Results and Analysis

According to the ABET, mechanical engineering students have to meet program objectives like the ability to apply knowledge of mathematics, science, and engineering, and the ability to engage in life-long learning. The assessment of the previous learning outcome was carried out in three case studies in the heat transfer course at Universidad del Atlántico, where 60 undergraduate Mechanical engineering students worked on finned surfaces to obtain knowledge and skills to analyze the efficiency, effectiveness, temperature profile and the total heat loss of 8 fins, in term of precision, clarity and relevance according to the rubric shown on table 1, where the criteria was assessed in a scale composed by 4 ranges, with 5 being the maximum score and 0 the minimum.

Table 1. Rubric used to evaluate the student performance.

Criteria	Excellent	Good	Regular	Deficient	Experimental Group			Control Group		
					Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Clarity	The answer given is understandable, expresses very clearly what it mean. It is expected to be met in 100%.	It is expected to be met in more than 80%.	It is expected to be met in more than 60%.	It is expected to be met in less than 60%.						
Precision	The answer given is specific, present details. It is expected to be met in 100%.	It is expected to be met in more than 80%.	It is expected to be met in more than 60%.	It is expected to be met in less than 60%.						
Relevance	The answer given consider the factors or aspects that are closely related to the question asked. It is expected to be met in 100%.	It is expected to be met in more than 80%.	It is expected to be met in more than 60%.	It is expected to be met in less than 60%.						

The academic course was divided in a control and an experimental group. A first test was applied to the groups twice based on a quasi-experimental design, starting by solving the three cases without the aid of the software, to see the homogeneity of the population in term of precision, clarity and relevance as shown on Table 2. The *t*-test was performed with a significance level of 0.05 for two samples with unequal variances and one normal population. The *P* values indicate that the groups are equal in terms of the criteria studied ensuring population homogeneity prior to intervention. In order to evaluate the difference between the average score between the control group and the experimental group, which used the software to solve three case studies, the t-test was performed again.

Table 2. Statistical analysis of both groups in the previous test.

DEPENDENT VARIABLES	N	CONTROL GROUP				EXPERIMENTAL GROUP				Value P	Tcrit	T
		H	SD	MIN	MAX	H	SD	MIN	MAX			
Clarity	45	2,68	0,29	2,27	2,95	2,76	0,18	2,43	2,99	0,8680	2.05	0.13
Precision	45	2,24	0,21	2,43	2,87	2,59	0,21	2,05	3,12	0,8571	2.05	0.19
Relevance	45	2,76	0,25	2,39	3,32	2,69	0,28	2,53	3,13	0,3213	2.05	1.54

Note: H=Half, S.D. = standard deviation, Tcrit. = T Critical value

Table 3 shows the statistical results for the data obtained in both groups after the intervention of the experimental group, and it is observed that all *P* values indicates that there is a difference between the mean scores of the groups, suggesting that the software has a significant positive effect on the learning process of the students.

Table 3. Statistical analysis of both groups after the intervention.

DEPENDENT VARIABLES	N	CONTROL GROUP				EXPERIMENTAL GROUP				Value P	Tcrit	T
		H	SD	MIN	MAX	H	SD	MIN	MAX			
Clarity	45	2,84	0,24	2,48	3,39	4,18	0,32	3,76	4,74	0,00	2.21	14.26
Precision	45	2,81	0,26	2,69	3,54	4,07	0,22	3,65	4,67	0,00	2.21	11.38
Relevance	45	2,76	0,29	2,58	3,39	4,21	0,29	3,54	4,68	0,00	2.21	9.54

Note: H=Half, S.D. = standard deviation, Sig. = Level of significance, E.T. = Typical error

The three case studies solved with the assistance of the *ProfileFins* program are presented as follow:

3.1 Influence of thermal conductivity on temperature profile

Table 4 shows the input parameters used in a straight triangular fin for 3 different values of thermal conductivity.

Table 4. Input parameters for straight triangular fin.

Symbol	h, (Btu/ (ft^2 °F)	T_b ,(°F)	T_a ,(°F)	L,(in)	Th,(in)	W,(in)
Value	15	1100	100	12	1	1

In figure 2, the length of 0 feet indicates the extreme of the fin and 1 feet indicate the base. According to the temperature profile shown it is recommended to use materials whose thermal conductivity values are high in order to increase the heat loss between the fin and the surrounding fluids. The highest rate of heat loss is obtained in the interval 0.6 to 1 because of the degree of inclination of the curves.

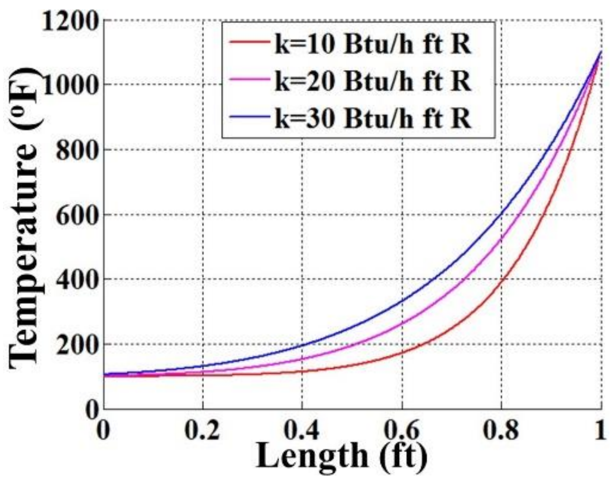

Figure 2. Effect of thermal conductivity in a straight triangular fin

3.2 Effect of the heat transfer coefficient and thermal conductivity on the total heat, effectiveness and optimum length of the fin.

Table 5 shows the input parameters used in a Cylindrical pin fin for 3 different values of thermal conductivity.

Table 5. Inlet parameters for the Cylindrical pin fin.

Symbol	K, [W/(m °K)]	h, [W/(m ^{2} °K)]	T_b, [ºC]	T_a ,[ºC]	L, [m]	D ,[m]
Value	14-180-398	100	25	100	0.3	0.005

Figure **3** shows the total heat behavior when the thermal conductivity of the material changes in a Cylindrical pin fin. It shows that the best result is obtained for high values of *k* where the heat loss is the highest with the best effectiveness. Depending of the amount of heat loss required this plot helps in the decision making of which fin to design because of the proper length.

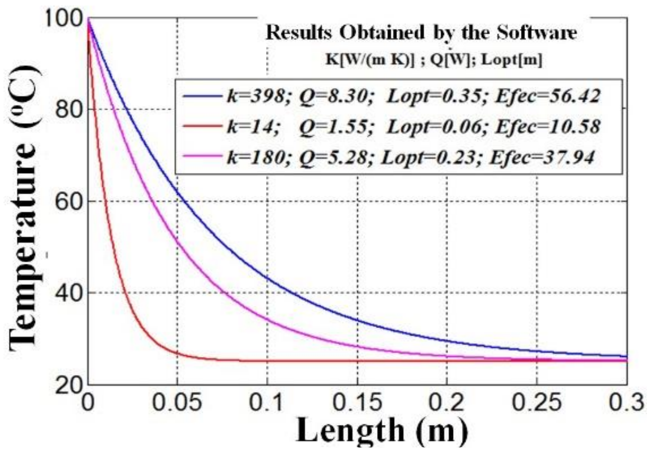

Figure 3. Temperature Profile Cylindrical Fin - Effect of Thermal Conductivity

3.3 Fin efficiency analysis

This section describes the different behaviors of efficiencies for 3 types of fins which were analyzed by the software. Input values were taken from case study 1. Table 6 shows the different values of efficiency and total heat transferred by the triangular fin as the relation straight length (L) / thickness (T) varies.

Table 6. Efficiency and heat loss for Triangular Straight Fin.

Relation L/T	16.60	14.20	12.50	11.11	10.00
Efficiency	0.13	0.14	0.15	0.16	0.17
Heat (Btu)	341	367	391	414	435

Note that the values are more feasible when the thickness of the fin is reduced and thus efficiency fin heat transfer and increase.

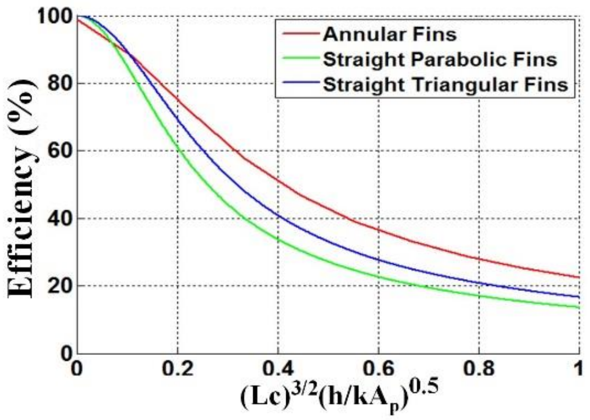

Figure 4. Efficiency triangular straight, annular, parabolic fin.

Figure 4 shows the efficiency profiles obtained for 3 different fin geometries as a function of the corrected length. Note that the straight triangular fin has the highest efficiency indicating the importance of the geometry.

4. Conclusions

The computational tool *ProfileFins* was introduced successfully in a Mechanical engineering class where the students evaluated their capacity to make an analysis of the design of different fins. Three case studies were made with the help of the software, Influence of thermal conductivity on temperature profile, Analysis of the effect of heat transfer coefficient and thermal conductivity on the total heat, effectiveness and optimum length of the fin, and Fin efficiency analysis. It was selected a population of 60 undergraduate students of mechanical engineering to make a statistical analysis. Two groups of 30 students were used, the control group and the experimental group, and with the use of the t-test they result equal in terms of clarity, precision and relevance ensuring homogeneity in the population. The P-value of the statistical analysis was lower than 0.05 indicating that there is a significant difference between the grades of both groups demonstrating that the software *ProfileFins* has an important effect in the student learning process.

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