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*by* UMB IJIMEAM

# HEAT DISTRIBUTION SIMULATION IN THE MATERIAL SQUARE PLATE ALUMINUM 7075 USING LAPLACE EQUATION WITH MATLAB APPLICATION

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**Abstract**

The management of heat transfer from aircraft engines to the wing is a crucial aspect of modern aircraft design to maintain thermal efficiency and structural integrity. The heat generated by aircraft engines can cause excessive heating of the wings, affecting aerodynamic performance and safety. Therefore, this study focuses on an in-depth understanding of the heat transfer analysis mechanisms. From previous research, the authors found it necessary to re-examine the heat distribution on a square plate, aiming to analyze the heat distribution on an aluminum 7075 plate using the Laplace equation applied through MATLAB. The main objective is to explore and understand the heat distribution process. This research uses a numerical method, applying the Laplace equation with the assistance of MATLAB Online Version 2023 software. Neumann boundary conditions are used to represent the boundary conditions at the plate edges, with modifications for heat transfer through insulation. The numerical solution is performed using the Liebmann method to achieve iterations with an error of less than 1%. Simulations are conducted on an aluminum 7075 plate measuring $4 \times 10^{-2}$ m x $4 \times 10^{-2}$ m with various temperature conditions at the plate edges. Numerical calculation results show that at the 9th iteration, the error reaches 0.71%, while calculations using MATLAB achieve an error of 0.4681% at the same iteration. The heat distribution on the plate can be clearly visualized, and the analysis indicates that increasing the number of grids enhances the clarity and accuracy of the heat distribution. In conclusion, this study demonstrates that the use of the Laplace equation and MATLAB application is effective in analyzing heat distribution on aluminum 7075 plates. Simulation results show that the more grids used, the more accurate and clear the resulting heat distribution, particularly with 101 grids where the heat distribution appears clear and accurate. These findings contribute to the development of more efficient thermal system designs in various technological applications, particularly in the aviation industry.

*Keywords*: *PDE, Laplace, Heat Distribution, Matlab*

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## 1. INTRODUCTION

Efficient heat transfer in aircraft is a key factor in enhancing thermal efficiency and maintaining the structural integrity of the aircraft. Aircraft engines generate significant heat during operation, making the management of heat transfer critical in modern aircraft design. The wings of the aircraft, as one of the main components, are particularly susceptible to excessive heating, which can affect aerodynamic performance and flight safety. This phenomenon creates design challenges that require an in-depth understanding of heat transfer mechanisms and the development of effective technological solutions[1].

Heat distribution in aluminum materials is crucial in the context of aircraft design due to aluminum's superior mechanical properties, such as high tensile strength and a good strength-to-weight ratio. This material is often used in aircraft structures, including wings, because it can withstand heavy loads while remaining lightweight, particularly aluminum 7075. However, aluminum 7075 also has relatively high thermal conductivity, making it essential to understand how heat is distributed and managed in this material to avoid issues like thermal deformation and material fatigue that could jeopardize flight safety.

Various previous studies have addressed certain aspects of heat transfer in the context of aviation, but more comprehensive research is still needed to delve deeper into optimal heat distribution and overheating prevention strategies. Therefore, this study seeks to fill this knowledge gap by conducting an in-depth analysis of heat distribution from aircraft engines to the wings using aluminum 7075 plates[2]. To understand the properties and characteristics of heat transfer, mathematical solutions are required. Research in this field employs various numerical methods, such as elliptic partial differential equations, facilitated by computer computation.

The phenomenon of heat distribution on a square plate describes the temperature distribution within a given domain. In a study by Lukman Samatowa et al. (2023), it was concluded that the temperature distribution from a heat flow model in a steady-state condition on a metal plate can be accurately represented using Microsoft Excel software[3]. Factors affecting the display and accuracy of temperature distribution on the metal plate in steady-state conditions include grid size selection, boundary conditions at each edge, and the presence of internal heat sources within the plate. Furthermore, Imam Noor et al. (2020) explained that the temperature distribution on thin brass plates is greater than that on thin iron plates[4]. Additionally, Yaochuang Han et al. (2023) noted that the accuracy of numerical results for the Stokes flow equation still depends on Gaussian quadrature[5]. Rachmawati, V. (2015) showed that differential equations can be solved using MATLAB and simulated the solutions of several partial differential equations[6].

It can be concluded that the research mentioned above shows that software such as Microsoft Excel can accurately model the temperature distribution on metal plates, influenced by grid size and boundary conditions (Lukman Samatowa et al., 2023). There are variations in heat distribution between brass and iron plates (Imam Noor et al., 2020). Numerical methods are very important for accurate analysis (Yaochuang Han et al., 2023), and partial differential equations can be solved using MATLAB (Rachmawati, 2015). However, further research is still needed regarding heat distribution in 7075 aluminum in aviation applications using the Laplace equation with MATLAB. Based on the previous research explanation above, the researcher considers it necessary to re-examine the distribution of heat on aluminum square plates in a more comprehensive manner regarding the distribution of heat on aluminum 7075 by applying the Laplace equation using MATLAB, which is still rarely found. This research attempts to fill this gap by conducting an in-depth analysis of the heat distribution from the aircraft engine to the wings using 7075 aluminum plate material.

This heat distribution analysis aims to explore and understand in more depth the heat distribution process on square plates, especially aluminum 7075 by applying the Laplace equation with the MATLAB application. With simulations and analysis using the Laplace equation and MATLAB applications, it is hoped that this research can provide better insight into the characteristics of heat distribution in the context of applications in materials to support the evolution of future aircraft that are more efficient and thermally safe. It is hoped that the results of this research can contribute to the development of efficient thermal system design and optimization in various fields of technology and engineering, especially in terms of heat distribution analysis in aircraft wing materials.

## 2. METHODOLOGY

This research uses a numerical method, specifically the Laplace equation, with the assistance of MATLAB Online Version 2023 software for numerical calculations as the basis for modeling. MATLAB provides a powerful and flexible programming environment for solving partial differential equations and other numerical methods. In this context, Neumann boundary conditions are used to represent the boundary conditions at the plate edges, while insulation is applied to modify heat transfer with the surrounding environment. This combination creates a realistic and relevant simulation environment for real-world conditions. Additionally, this research uses the Liebmann method for numerical solutions to achieve iterations with an error of less than 1%[7]. The Liebmann method is a simple and effective numerical technique for solving the Laplace equation iteratively, well-suited for analyzing heat distribution on metal plates such as aluminum 7075[8]. Its main advantages include ease of implementation, memory usage efficiency, and stable convergence that can be enhanced with relaxation parameters. This method is also flexible, capable of handling various boundary conditions and complex domain geometries. With these advantages, the Liebmann method proves reliable in heat transfer modeling, supporting the development of more efficient and accurate thermal designs for engineering applications, including in the aviation industry. The use of MATLAB in this research also offers advantages in terms of speed, accuracy, and flexibility in applying numerical methods to solve the Laplace equation[9].

The boundary conditions applied in this research have significant physical relevance to real-world scenarios. Neumann boundary conditions, which describe plate edges with constant or zero temperature gradients, are suitable for modeling thermally insulated aircraft wing parts to prevent heat loss. Meanwhile, Dirichlet boundary conditions, which set fixed temperatures at the plate edges, describe wing parts in direct contact with the engine or other heat sources, ensuring a realistic representation of heat distribution within the aircraft structure. Applying these boundary conditions helps create accurate and relevant simulations, providing important insights for efficient and safe thermal design. Below is a diagram of the computational domain with the applied boundary conditions:

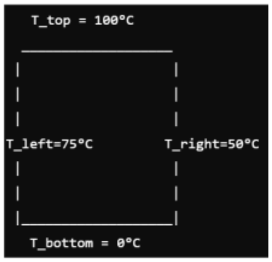


**Figure 1** Computational domain diagram with applied boundary conditions

The heat distribution process is assumed to occur on a plate measuring 4x10$^{-2}$ m x 4x10$^{-2}$ m made of 7075 aluminum plate[10]. Initially, the plate had a right temperature limit of 50$^0$C, left 75$^0$C, above 100$^0$C and below 00C. This assumption implies that the bottom side is insulated with a constant temperature. The temperature points measured on the plate are located on the four sides of the edge of the plate. The research process involves steps such as establishing a mathematical model for temperature distribution on a thin plate, converting analytical equations to numerical form using the Laplace equation finite difference method, carrying out computational calculations using MATLAB from numerical equations, analyzing heat distribution profiles, and compiling reports as a result of this research[11].

## 3. RESULTS AND DISCUSSION

### 3.1 Numerical Methods

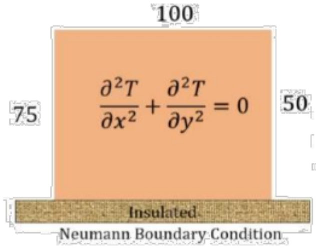
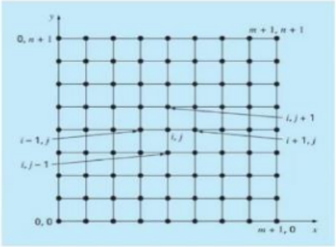


**Figure 2**. Aluminum 7075 thin plate elements are in equilibrium

The plate is heated to a certain temperature with $\lambda$=1.5 and Ɛs=1%.

Liebman method:



Chapra & Canale (2014)
Numerical Methods for Engineers

**Figure 3**. Use of grids in graphs of Laplace's equation

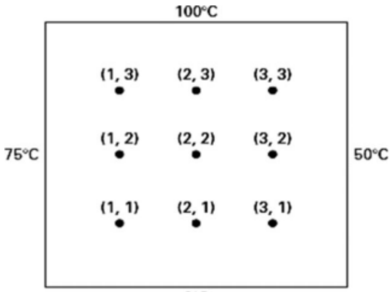


**Figure 4**. Boundary conditions

Numerical solution:

1st iteration

$$T_{i,j} = \frac{T_{i+1,j} + T_{i-1,j} + T_{i,j+1} + T_{i,j-1}}{4} \quad (1)[7]$$

$$T_{11} = \frac{0 + 75 + 0 + 0}{4} = 18{,}75$$

$$T_{i,j}^{new} = \lambda T_{i,j}^{new} + (1 - \lambda) T_{i,j}^{old} \quad (2)[12]$$

$$T_{11} = 1{,}5(18{,}75) + (1 - 1{,}5)0 = 28{,}125$$

For i=2, j=1

$$T_{21} = \frac{0 + 28{,}125 + 0 + 0}{4} = 7{,}03125$$

$$T_{21} = 1{,}5(7{,}03125) + (1 - 1{,}5)0 = 10{,}54688$$

For i=3, j=1

$$T_{31} = \frac{50 + 10{,}54688 + 0 + 0}{4} = 15{,}13672$$

$$T_{31} = 1{,}5(15{,}13672) + (1 - 1{,}5)0 = 22{,}70508$$

Because all the T's$_{i,j}$ starting with zero, all Ɛa for the first iteration become 100%, for error $T_{1,1}$ can be calculated as follows:

$$(\varepsilon_a)_{1,1} = \left|\frac{32,51953 - 28,125}{32,51953}\right| 100\% = 13,5\%$$

Because the error value is above 1% (13.5%>1%), the calculation is continued until the error value is obtained≤1%. After the calculations were carried out, the results were obtained in the 9th iteration for errors<1% i.e. 0.71%

For error T1,1 in the 9th iteration it can be calculated as follows:

$$(\varepsilon_a)_{1,1} = \left|\frac{43,000 - 42,995}{43,000}\right| 100\% = 0,71\%$$

Table 1. 9th Iteration Calculation Results

| Node Temperature | | |
|---|---|---|
| T11=43,00 | T21=33.30 | T31=33,89 |
| T12=63,21 | T22=56,11 | T32=52,34 |
| T13=78,59 | T23=76,06 | T33=69,71 |

**Source:** Numerical Calculation Data (2024)

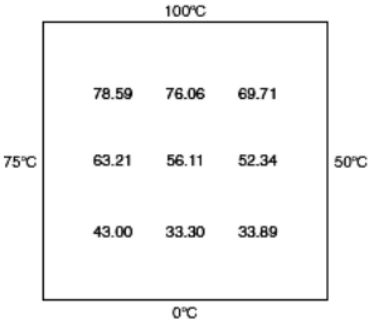


**Figure 5**. Heat distribution on the plate as a result of numerical calculations

From the calculations using the numerical method on a heated plate with specified boundary conditions 100°C on the top edge, 50°C on the right edge, 75°C on the left edge, and 0°C on the bottom edge it is observed that the results obtained using the Liebmann method show that the error value drops below 1% at the 9th iteration, with a final error of 0.71%. When using MATLAB, the error at the 9th iteration is recorded as 0.4681%.

## 3.2 Use of Matlab Applications

Using the MATLAB application, an error of less than 1%, specifically 0.4681%, was obtained at the 9th iteration. The processed data are as follows:

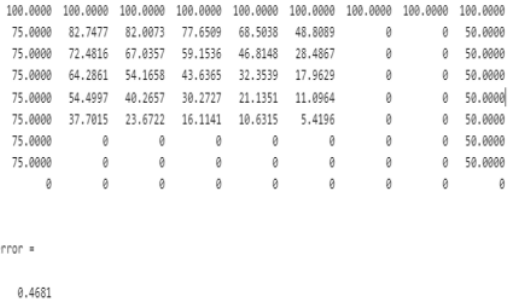
```
for i=1:9;
   for j=1:9;
      T(i,j)=0
   end
end

%BOUNDARY CONDITIONS
T(:,1)=75 ; %batas kiri
T(:,j)=50 ; %batas kanan
T(1,:)=100 ; %batas atas
T(j,:)=0 ; %batas bawah

lamda = 1.5

while(1)
   for j=2:6
      for i=2:6
         T_old(i,j)=T(i,j);
         T(i,j)=(T(i+1,j)+T(i-1,j)+T(i,j+1)+T(i,j-1))/4;
         T(i,j)=lamda*T(i,j)+(1-lamda)*T_old(i,j)
      end
   end
   error=dot((((T(i,j)-T_old(i,j))/T(i,j))*100),...
      (((T(i,j)-T_old(i,j))/T(i,j))*100))
   if error<=1
      break;
   end
end
```

Table 2. Results of the 9th Iteration Calculation Using MATLAB



```
 100.0000  100.0000  100.0000  100.0000  100.0000  100.0000  100.0000  100.0000  100.0000
  75.0000   82.7477   82.0073   77.6509   68.5038   48.8089         0         0   50.0000
  75.0000   72.4816   67.0357   59.1536   46.8148   28.4867         0         0   50.0000
  75.0000   64.2861   54.1658   43.6365   32.3539   17.9629         0         0   50.0000
  75.0000   54.4997   40.2657   30.2727   21.1351   11.0964         0         0   50.0000
  75.0000   37.7015   23.6722   16.1141   10.6315    5.4196         0         0   50.0000
  75.0000         0         0         0         0         0         0         0   50.0000
  75.0000         0         0         0         0         0         0         0   50.0000
        0         0         0         0         0         0         0         0         0


error =

    0.4681
```

**Source:** The 9th iteration calculation uses the online version of MATLAB

Data was obtained to analyze the temperature of the plate which consists of four parts, namely at the top of the 100 plate$^0$C, right side 50$^0$C, left part 75$^0$C and below 0$^0$C.

### 3.2.1 Matlab 5 grid analysis results

The following is a program/pseudocode or MATLAB code snippet to determine the heat distribution on 5 grids:

```
clc;clear;close all;
x0=0; xf=1;
y0=0; yf=1;

nx = 5; ny = 5; %checking for ref book
2
x=linspace(x0,xf,nx);
y=linspace(y0,yf,ny);
dx=x(2)-x(1);
dy=y(2)-y(1);

T=zeros(nx,ny); %preallocation matrix

kmax = 1e5;%number of iteration,
%try until the result gives a constan value or graphic
%A higher number of iterations make better result
% I suggest using k=10000, (it may be taking more CPU time but give a good result

for k = 1:kmax % perform iterative calculation
   for i = 2:nx-1
      for j = 2:ny-1
         T(i,j)=((dy^2*(T(i+1,j)+T(i-1,j)))+(dx^2*(T(i,j+1)+T(i,j-1))))/(2*(dx^2+dy^2));
      end
   end
   T(:,1)=75; %Left BC
   T(:,ny)=50; %Right BC
   T(1,:)=100; %Top BC
   T(nx,:)=(4.*T(nx-1,:)-T(nx-2,:))/3; %Neumann BC
end

figure (1)
imagesc(x,y,T)
title('Profile Temperature in square Plate')
xlabel('x-axis')
ylabel('y-axis')
colormap jet
colorbar
```

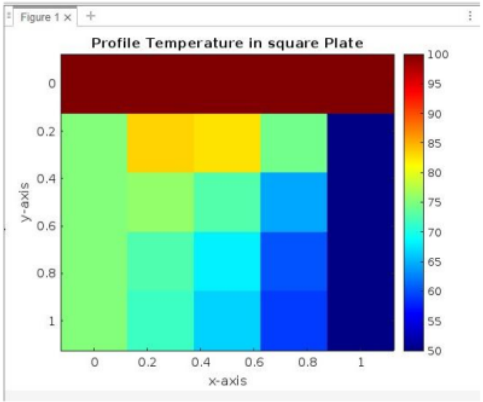


**Figure 6.** Heat Distribution on a 5 grid division plate

### 3.2.2 Matlab 81 grid analysis results

The following is a program/pseudocode or MATLAB code snippet to determine the heat distribution on 81 grids:

```
clc;clear;close all;
x0=0; xf=1;
y0=0; yf=1;

nx = 81; ny = 81; %checking for ref book
2
x=linspace(x0,xf,nx);
y=linspace(y0,yf,ny);
dx=x(2)-x(1);
dy=y(2)-y(1);

T=zeros(nx,ny); %preallocation matrix

kmax = 1e5;%number of iteration,
%try until the result gives a constan value or graphic
%A higher number of iterations make better result
% I suggest using k=10000, (it may be taking more CPU time but give a good result

for k = 1:kmax % perform iterative calculation
   for i = 2:nx-1
      for j = 2:ny-1
         T(i,j)=((dy^2*(T(i+1,j)+T(i-1,j)))+(dx^2*(T(i,j+1)+T(i,j-1))))/(2*(dx^2+dy^2));
      end
   end
   T(:,1)=75; %Left BC
   T(:,ny)=50; %Right BC
   T(1,:)=100; %Top BC
   T(nx,:)=(4.*T(nx-1,:)-T(nx-2,:))/3; %Neumann BC
end

figure (1)
imagesc(x,y,T)
```

```
title('Profile Temperature in square Plate')
xlabel('x-axis')
ylabel('y-axis')
colormap jet
    colorbar
```

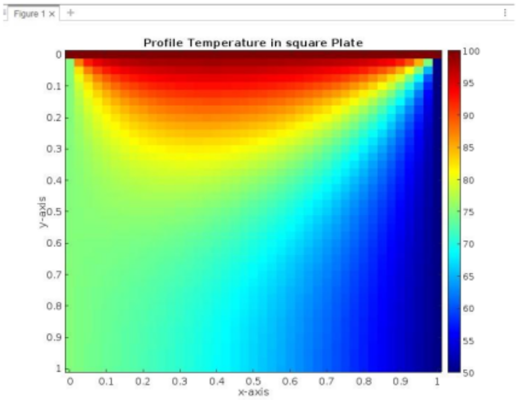


**Figure 7.** Heat Distribution on the 81grid division plate

3.2.3 Matlab 101 grid analysis results

The following is a program/pseudocode or MATLAB code snippet to determine the heat distribution on 101 grids:

```
clc;clear;close all;
x0=0; xf=1;
y0=0; yf=1;

nx = 101; ny = 101; %checking for ref book
2
x=linspace(x0,xf,nx);
y=linspace(y0,yf,ny);
dx=x(2)-x(1);
dy=y(2)-y(1);

T=zeros(nx,ny); %preallocation matrix

kmax = 1e5;%number of iteration,
%try until the result gives a constan value or graphic
%A higher number of iterations make better result
% I suggest using k=10000, (it may be taking more
CPU time but give a good result

for k = 1:kmax % perform iterative calculation
  for i = 2:nx-1
    for j = 2:ny-1
      T(i,j)=((dy^2*(T(i+1,j)+T(i-
1,j)))+(dx^2*(T(i,j+1)+T(i,j-1))))/(2*(dx^2+dy^2));
    end
  end
  T(:,1)=75; %Left BC
  T(:,ny)=50; %Right BC
  T(1,:)=100; %Top BC
  T(nx,:)=(4.*T(nx-1,:)-T(nx-2,:))/3; %Neumann BC
end

figure (1)
imagesc(x,y,T)
title('Profile Temperature in square Plate')
xlabel('x-axis')
ylabel('y-axis')
colormap jet
colorbar
```

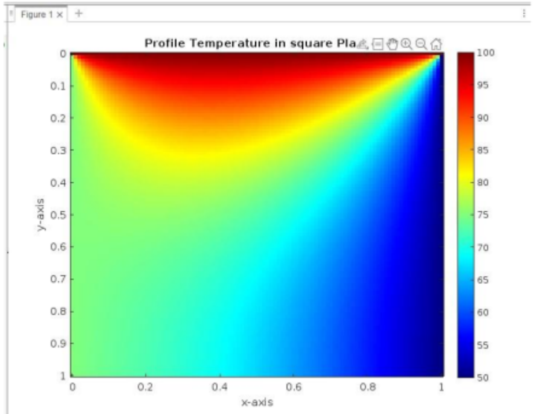


**Figure 8.** Heat Distribution on a 101 grid division plate

Therefore, the simulation results using MATLAB demonstrate high consistency with similar studies using other software such as Excel, with minimal differences in outcomes. Larger discrepancies observed in studies with different materials underscore the importance of considering material properties in thermal simulations. MATLAB has proven to be a reliable and accurate tool for modeling heat distribution, supporting better thermal design for aerospace and other engineering applications.

Using MATLAB, the simulation results show detailed temperature distributions with various grid sizes. It can be observed from the visualization of heat distribution results with different grid divisions above that the highest temperature is located at the top edge of the plate, decreasing towards the bottom edge. This aligns with the specified boundary conditions and the fundamental principles of heat transfer from areas of high temperature to low temperature. These results indicate that sections of the plate adjacent to the heat source (aircraft engine) experience higher temperatures, while those farther away experience lower temperatures.

This heat distribution pattern is very relevant for the thermal design of aircraft wings. Wing parts located close to the engine must be designed to withstand high temperatures without loss of structural integrity or aerodynamic performance. Materials such as aluminum 7075, used in this research, exhibit predictable and well-controlled temperature distribution, making them suitable materials for this application. Application of these results helps in designing more efficient and safer aircraft wings, ensuring even heat distribution and avoiding hotspots that could cause damage or structural failure.

## 4. CONCLUSION

From the calculations and simulations above, it can be concluded that the heat distribution process on the Aluminum 7075 square plate material by applying the Laplace equation in the 2023 version of the MATLAB Online application, data was obtained that the calculations were carried out using numerical methods, results were obtained in the 9th iteration for error <1%, namely 0.71%, whereas if you use the Matlab application in the 9th iteration you get an error of <1%, namely 0.4681%. The heat distribution in equilibrium conditions on an aluminum metal plate can be described clearly and accurately using MATLAB, this can help in understanding the temperature distribution pattern in this material. Then, comparison with similar studies shows the consistency of the results, with minimal differences caused by different numerical precision and material properties.

Some factors that influence the appearance and accuracy of heat distribution on a metal plate under equilibrium conditions involve determining the grid size and boundary conditions at the edges of the plate. Based on the MATLAB simulation results on grid 101, the heat distribution on the plate is clearly visible, thus the more grids that are specified or displayed, the clearer and more accurate the heat distribution will be. The results of this analysis provide important insights into the heat distribution in aircraft wing materials, which is critical for efficient thermal design. A better understanding of temperature distribution patterns can help engineers design aircraft components that resist heat and ensure optimal performance. The use of materials such as 7075 aluminum, which exhibits well-controlled temperature distribution, can improve the safety and operational efficiency of aircraft. This research also emphasizes the importance of simulation software such as MATLAB in facilitating in-depth thermal analysis and supporting the development of more advanced aviation technologies.

However, there are several limitations in this heat distribution analysis, where this simulation uses a grid of a certain size which can affect the final results, and uses fixed boundary conditions, while in real world applications, boundary conditions can change over time. So further research is needed that can explore grids with higher resolution.

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