Team 4: Test Fixture for Flight Components

Quartz Lamp Analysis

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Introduction

The Test Fixture for Flight Components project requires Team 4 to design a test fixture that will be used to evaluate a missile radome's performance. The radome is the nose of a missile and is subjected to a majority of the flight conditions. In flight, the radome is under high force and high heat. The test fixture must generate a realistic simulation of force and heat in order for the radome to be evaluated properly. The team has decided to apply force with electromagnetism and heat with quartz lamps. This report will focus entirely on quartz lamps and their ability to reproduce reasonable values for heat flux.

In flight, a radome can experience up to 300 degrees Fahrenheit. It is clear that quartz lamps can reach this temperature [1]. Quartz lamps may not produce similar heat flux to what is experienced in flight. Because of this, the heat flux calculation is necessary to see if the value is comparable to those from flight conditions. Another issue is that, during flight, the temperature profile is uniform. Since the quartz lamps are flat, they will produce natural points of concentration as shown in Figure 1 below.

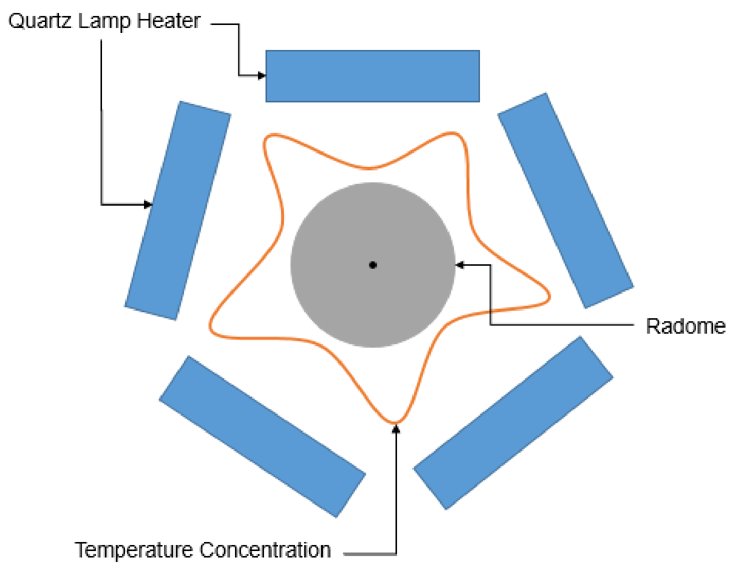

Figure 1: Quartz Lamp Temperature Concentration

This report contains a detailed analysis of quartz lamps their heat flux through surfaces. The number of quartz lamp units and their geometries to account for temperature profile differences will need to be included in a separate analysis.

Quartz Lamp Heater Model

Each quartz lamp heater is composed of six quartz lamps. Quartz lamps are cylindrical tubes that contain a quartz envelope and a tungsten filament [2]. The filament acts as the primary source of energy while the quartz envelope obtains most of its energy from the filament's radiation [2]. The quartz envelope is considered the secondary source of energy [2]. A cross-sectional view of a quartz lamp can be found in Figure 2 below.

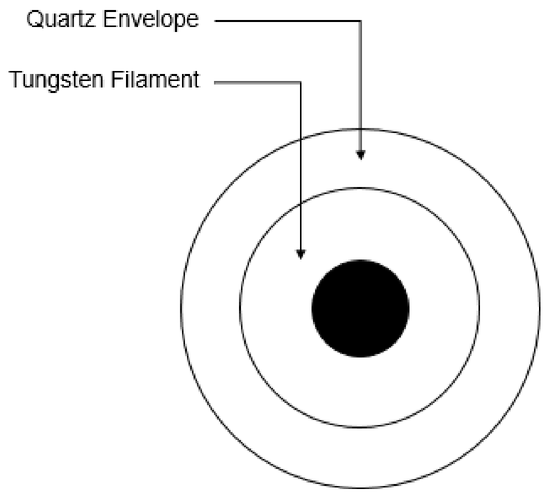

Figure 2: Quartz Lamp Cross Section

The quartz lamp heaters surround the six quartz lamps in a reflector [2]. The reflector is a titanium parabolic sheet that enhances the energy produced by the lamps [2]. The lamps are aligned in parallel as shown by the cross-sectional view in Figure 3.

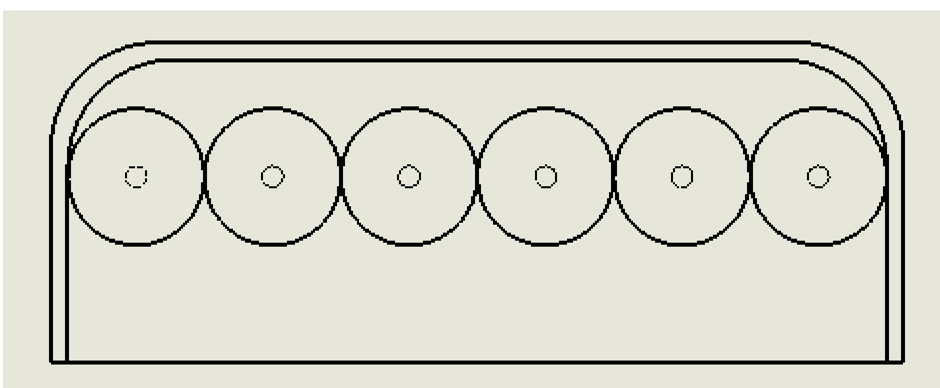

Figure 3: Quartz Lamp Heater Cross Section

This analysis was conducted with the geometry shown above in mind. Details of the heat flux calculation are incorporated into the following section.

Assumptions and Equations

The goal of this analysis is to obtain estimated heat flux values. Precise values are not necessary because heat flux can be adjusted if it falls within a general range. This analysis was conducted with specific assumptions in mind that simplify calculations. All assumptions can be found in the numbered list below.

1. Each heater contains six lamps [2].
2. Each lamp has a length of 24.77 cm [2].
3. Each lamp has a diameter of 1.28 cm [2].
4. The height from the radome to the quartz lamp heater is 16 cm (constant) at any given point.
5. The six lamps are aligned in parallel touching each other (see Figure 3 above).
6. The system is a black body: All radiation from the lamp is directed towards the flight component.
7. The lamp is the only source of radiation: Radiation from all other sources is ignored.
8. The system is diffuse: Irradiation is independent of direction.
9. The system is gray: Irradiation is independent of wavelength.
10. Any excess radiation is lost: radiation reflected or absorbed back into the lamp.
11. The radome is a flat plate: heat flux is calculated for a flat plane.

The assumptions above drive the calculations for heat flux. The heat flux varies based on position, so the equation for the heat flux is in terms of *x* and *y* [2]. The position matters because the reflector has a greater impact on the lamps that are located on the edges of the heater [2]. This causes a difference in heat flux. The heat flux equation can be found in equation 1 below [2].

$$q(x,y) = \frac{Q_b H}{2\pi^2 L\alpha}\left(\frac{\beta}{\beta^2+\alpha^2} - \frac{\gamma}{\gamma^2+\alpha^2} + \frac{1}{\alpha}\tan^{-1}\left(\frac{\beta}{\alpha}\right) - \frac{1}{\alpha}\tan^{-1}\left(\frac{\gamma}{\alpha}\right)\right) \tag{1}$$

α, β, and γ represent equations in terms of *x* and y [2]. They account for the cylindrical shape of the quartz lamps [2]. These supplemental equations can be found in Equation 2, Equation 3, and Equation 4 respectively [2].

$$\alpha = \sqrt{y^2 + H^2} \tag{2}$$

$$\beta = x + \frac{L}{2} \tag{3}$$

$$\gamma = x - \frac{L}{2} \tag{4}$$

Q_0 is the initial heating rate of the system. Since the system is assumed to be a black body, Q_0 is denoted Q_b. The equation for the heating rate can be found in Equation 5 below.

$$Q_b = \sigma A T^4 \tag{5}$$

All variables and their descriptions can be found in the numbered list below.

1. $q(x,y)$ – Local heat flux in terms of *x* and *y* [2].
2. Q_b – Initial heating rate for a black body.

3. *A* – Surface area of the quartz lamp heater (*A* = 1902.336 cm^2) [2].
4. *α, β, γ* – Position equations in terms of *x* and *y* [2].
5. *H* – Height from the lamp to the plane of interest.
6. *L* – Lamp length (*L* = 24.77 cm) [2].
7. *x* and *y* – Position coordinates.
8. *T* – Initial temperature (*T* = 573.15K) [2].
9. *σ* – Stefan-Boltzmann constant ($\sigma = 5.67 \times 10^{-12}$ W/cm^2K).

x values range from 0 cm to 24.77 cm and *y* values range from 0 cm to 7.68 cm [2]. These values come from the length of the lamps and the sum of the six diameters respectively. Figure 4 below shows the coordinate system and how the quartz lamp heater is positioned for this analysis.

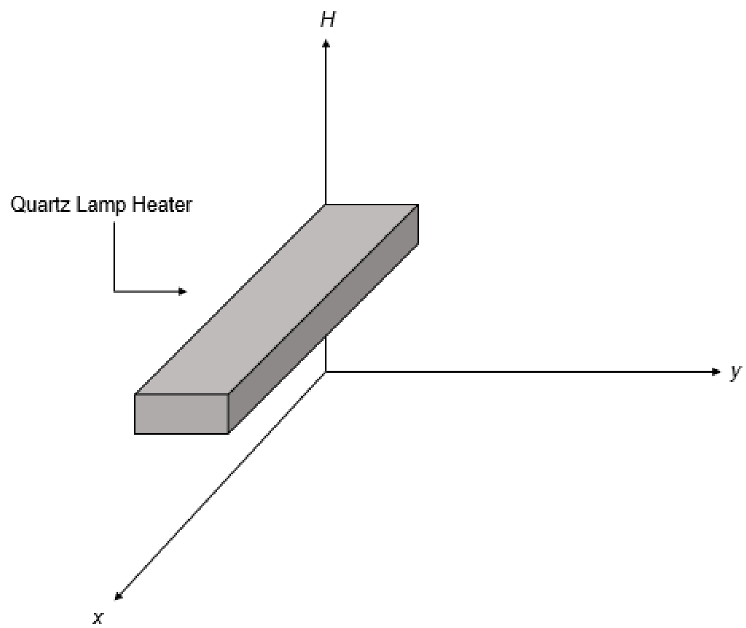

Figure 4: Quartz Lamp Position

These assumptions and equations allow for an estimated heat flux. The heat flux was calculated at various points in the coordinate system shown above. 25 total points were used in this analysis which is outlined in the following section.

Calculations

A MATLAB code was used to calculate the total local heat flux from one quartz lamp heater. It calculates heat flux at each of the 25 points mentioned earlier and then outputs the sum of all 25 values. Figure 5 below shows the process that was used to produce the output [2]. The full-length code can be found in the appendix.

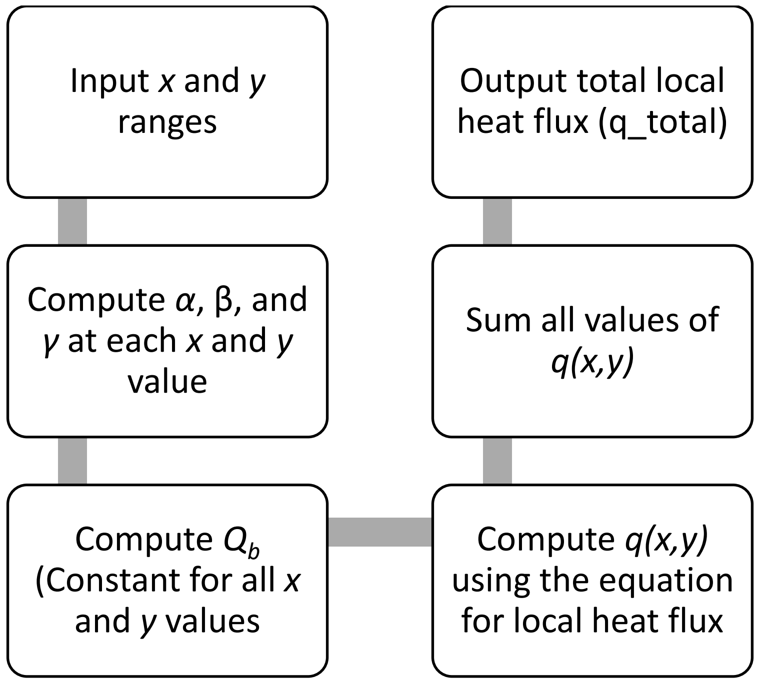

Figure 5: MATLAB Computing Process

This code was created to be used in future analyses by the team if necessary.

Conclusion

The result from the MATLAB program was 5.18 W/cm^2. This is a reasonable estimate of the heat flux from one lamp [2]. The test fixture will incorporate more than one lamp, which makes this calculation a conservative estimate. The addition of more lamps will increase the heat flux, which is necessary to reproduce flight conditions. Ahmad has conducted an analysis on the heat flux that radomes are subjected to in flight. The team will examine this analysis as well as Ahmad's analysis to determine how many heaters will be needed to duplicate the correct heat flux. This future computation will be included in a separate analysis that will be performed at a later date.

References

[1] R. Fields, "Flight Vehicle Thermal Testing With Infrared Lamps," *NASA Technical Memorandum 4336,* 1992.

[2] R. A. Travis Turner, "Numerical and Experimental Analysis of the Radiant Heat Flux Produced by Quartz Heating Systems," NASA, Hampton, 1994.

Appendix

```matlab
% Constant Values
L=24.77;                    %Length of lamp
sigma=5.67e-12;             %SB const W/cm^2K^4
H=16;                       %Distance from lamp to radome (cm)
T=573.15;                   %Temperature in Kelvin
A=1902.336;                 %Area of heater

% Position Values
x=0:L;                      %Position values in the x dir
y=0:.31:7.68;               %Position values in the y dir

% Geometry Equations
alpha=sqrt((y.^2)+(H.^2));
beta=x+(L/2);
gamma=x-(L/2);

% Initial Heating Rate Formula
Qb=sigma*A*(T^4);

% Local Heat Flux Formula (W/cm^2)
q=((Qb.*H)./(2.*(pi.^2).*L.*alpha)).*((beta./((beta.^2)+(alpha.^2)))-(gamma./((gamma.^2)+↙
(alpha.^2)))+((1./alpha).*atan(beta./alpha))-((1./alpha).*atan(gamma./alpha)));

%Total Local Heat Flux
q_total=sum(q);
disp(q_total)
```

Figure 6: MATLAB Code