THE INFLUENCE OF AERODYNAMIC HEATING AT THE OPTICAL PERFORMANCE OF MISSILES

Leite Junior, Paulo Roberto
Comando Geral de Tecnologia Aeroespacial (CTA)/ Instituto de Aeronáutica e Espaço (IAE)/ Divisão de Sistemas de Defesa(ASD)
DENEL Aerospace System / South Africa
prleitejunior@yahoo.com.br

Silva, Maurício Guimarães da
Comando Geral de Tecnologia Aeroespacial (CTA)/ Instituto de Aeronáutica e Espaço (IAE)/ Divisão de Sistemas de Defesa(ASD)
DENEL Aerospace System / South Africa
maugsilva@iae.cta.br

José Antonio Perrella Balestieri
São Paulo State University - UNESP
Energy Department
perrella@feg.unesp.br

***Abstract.** The influence of the aerodynamic heating for a missile dome flying at supersonic speed is evaluated in respect to optical performance. This aerodynamic heating is defined as the rise in temperature of the air adjacent to the external surface of a missile due to compression and friction. At high speeds, the external temperature of the missile can affect the design of the missile system and introduce problems with regard to the insulation of certain sub-systems. While it appears relatively easy to calculate the aerodynamic heating due to compression and friction the actual wall temperature attained is more difficult problem, and most likely a transient one. Further factors need to be included when attempting to estimate the skin temperature of a supersonic missile; these include factors such as radiation and conduction. This study looks at the interaction of these various factors and their application to the missile heating problem using a mixed of classical relations provided in the literature to this type of problem and Computation Fluid Dynamic(CFD) techniques. The finite difference method is then used to solve the resulting equations and the temperature distributions at the dome and inside it are obtained. Using the dome internal temperature distribution, the performance degradation of the optical system is estimated in terms of the energy focused on the detector. Using the software for optical simulations named ZEMAX, the system is designed to suit the temperature range in order to achieve the specified performance.*

***Keywords:** aerodynamic heating, missile technology, optical performance and Parametric Identification System*

1. Introduction

A supersonic missile experiences aerodynamic heating as a result of the conversion of air velocity into heat via the compressibility of the air through which it moves and the viscous forces acting in the boundary layer that surrounds the missile. The amount of heat generation depends directly on the speed of the missile and increases with speed. The ratio between the two modes of heat generation varies along the missile. Near the stagnation point, the heat generated by direct compression of the air will dominate while on the sides of the missile the conversion of velocity into heat by the viscous forces within the boundary layer will be dominant. For a high-speed missile, this heat generation can be significant. However, it is not the only consideration when determining the effects of aerodynamic heating. The influence of the aerodynamic heating on the dome of a missile flying at supersonic speed has a negative effect on optical system performance since the thermal characteristics of material of optical components, dome and air inside of dome change during the flight (transient behavior). Under these conditions, the performance of the optical system, obtained from the changes in dimensions of the lenses, is degraded in terms of the energy focused on the detector (Rainer et all., 2007). In this context, the objective of this paper is to present a mixed methodology based on CFD (Computational Fluid Dynamic) and PSI (Parametric System Identification) to analyze the influence of the aerodynamic heating on the optical system of a general missile, in respect to the optical performance. The pressure distribution is obtained from CFD technique in an Euler context. From these values, the fluid flow properties are obtained from semi-empirical relations. Since the thermal characteristics of the material change during the flight, a transient one-dimensional is applied. The loss parameter associate to the heat dissipation is obtained from PSI which uses experimental data in the identification process. The finite difference method, implemented in a context of MATLAB®, is then used to solve the resulting equations and the temperature distributions at the dome and inside it are obtained. Using the dome internal temperature distribution, the performance degradation of the optical system, obtained from the changes in dimensions of the lenses, is estimated in terms of the energy focused on the detector. Using the software for optical simulations named ZEMAX®, the system is re-designed to suit the temperature change in order to keep the initial specified performance.

2. Optical Design

The dome is the first optical component and is designed to have very low magnification and to be uniform in all its extension; otherwise it will distort the image that reaches the internal optical system. That is because the optical system does not stay pointed to only one position in the dome, but it can move in a large field of view, sometimes 75^o or more, inside the dome. The material to be used in the dome will be magnesium fluoride (MgF_2). MgF_2 domes are widely used due the good qualities of hardness and transparency in very wide spectra, from visible to medium infrared (MIR). Besides, the knowledge in manufacturing and availability are also good characteristics that determine the option for MgF_2.

Once the dome material is chosen, it is very important to define the optical system to be designed and simulated. The most common and efficient system used is the Cassegrain. Although there are many variations for this system, no specific model will be used. Instead, the program used to make the design will optimize the best configuration. The software used in this design is called ZEMAX®. It is a very powerful program widely used, due to its characteristics of optimization and friendly interface.

The Cassegrain optical system was designed in the 17th century to be applied in astronomical telescopes. The system used in that time was purely catoptrics, e.g., made only using mirrors. The advantage in using mirrors is settled in the fact that mirrors do not introduce chromatic aberrations as lenses do and it is possible to achieve a shorter focal length, which reduces the space needed to construct the optical system. In the time of its invention, the catoptrics telescopes were very used, due to the low technology in manufacturing lenses and materials available. Today, its possible to combine even mirrors and lenses to produce systems catadioptrics, e.g., using both mirrors and lenses.

The option for a system catadioptric is the best solution in a missile. In an intuitive design, since the material of the dome has dispersion power, which implies in different refraction index for different wavelengths, the use of a lens to correct the chromatic aberrations effects is required. Besides, a front lens can improve parameters as f-number and focal ratio, which are related to aperture and focal length.

Once defined the type of optical system to be used, it is important to know the general optical requirements. Typically, the main requirements are related to wavelength, field of view, diameter of dome, operational temperature of dome, and so on. The dome must be uniform, so, as first requirement, the outer diameter is 150mm. Since it is mandatory uniformity, the inner diameter will be the value of the outer diameter minus two times the thickness. So the optical magnification will be very low and the dome will have the same optical power in all its extension.

The next step is to define the front lens. Depend on the shape of lens it is possible to specify spherical or aspheric (lens with a shape that is not purely spherical) elements. In this work is chosen aspheric lens, due its really great advantages. Defining only one side as aspheric, it will be possible, through simulations, achieve a very good performance in terms of energy and axial colour distance, which means lower chromatic aberrations levels.

As the last issue, the Cassegrain system will be defined as two mirrors with conic constants determined by ZEMAX™. There are no requirements for conic constants, so the program will find the best values to accomplish the requirements. In order to understand the concepts of conic constants and aspheric elements, Eq.(1) provide comprehension about that:

$$z = \frac{cr^2}{1+\sqrt{1-(1+\mathrm{k})\mathrm{c}^2\mathrm{r}^2}} + \sum_{i=1}^{n} \alpha_i r^i \ , \qquad (1)$$

where z is the surface coordinate, c is the curvature, r is the radial coordinate, k is the conic constant and α are the aspheric coefficients. For a pure spherical surface, the conic constant k and all the α coefficients are zero. If conic constant is less than –1, the surface will be a hyperbolas, -1 for parabolas, between -1 and 0 for ellipses, 0 for spheres, and greater than 0 for oblate ellipsoids. If the coefficients α are not zero, the surface will be aspheric. In this design, it is specified the aspheric configuration for front surface of the first lens and spherical shape for rear surface. It could be chosen both surfaces aspheric, however the price would be prohibitive. In terms of optimization, it will be allowed to change only the conic constants for the mirrors since the results will be oblate ellipsoids for both mirrors. In this context, Fig. 1 presents a first proposal about the optical system (drawn section of ¾), Leite Jr and Silva (2007).

The bigger element is the dome and it surrounds completely the optical system. Its function is to protect the optical system and, physically provide an aerodynamic streamline flow. The first element inside the dome is an aspheric lens ade using zinc sulphide in broad spectrum (ZNS_broad). This alternative is based on simple reasons: the ZNS_broad has very good optical properties, it is not expensive and its dispersion diagram allows a good match with MgF2, accordingly to ZEMAX® glass catalogs. Using this material, it was possible to reduce the axial color to less than 40 μm. That distance is great compared to high precision imaging systems. However, in this system, only one optical element is being used to correct chromatic aberration, and as it will be shown, that distance is smaller than the detector pixel size.

The next elements to be defined are the mirrors. Their role here is to focus the rays coming from the front lens into the detector. To construct the mirrors, the material to be used will be ZERODUR™. The reason is also simple: its thermal expansion coefficient is lower than $1x10^{-7}$ /^{o}C in the range between 20 ^{o}C and 300 ^{o}C, which means that even under great temperatures gradients the mirrors will not change considerably their thickness and curvature radii.

Finally, there is the detector. The detector is a matrix constituted of 14400 pixels arranged in 120 columns of 120 pixels each one. The size of each pixel is 60x60 μm, which provide a final image size of 7200 μm, or 7.2 mm. Consequently, the optical system must be able to generate a square image of 7.2x7.2 mm, achieving a 4.5^0 full field of view.

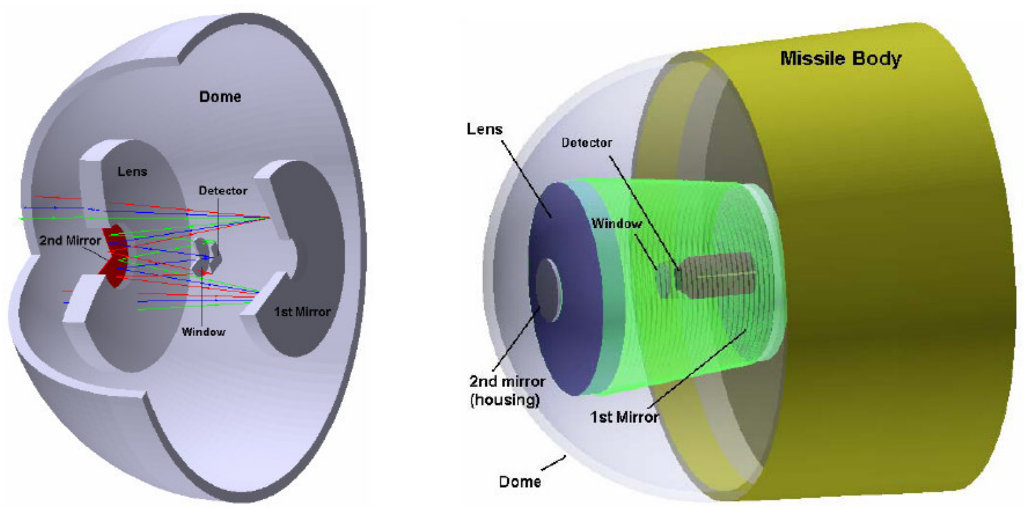

Figure 1 – Optical system proposed

2.1 Temperature at Dome Surface

One of the most important requirements to project an optical design is to determine the operational range in terms of gradient of temperature, which as, all elements at $-40C^0$ up to $80C^0$ to the inner elements and from $-40C^0$ to $300C^0$ to the external wall of the dome. Under so critical circumstances, it is very difficult to achieve a perfect optical design to the system. However, it will be shown that due to very low thermal expansion of the elements, a system can be designed to operate in such variation of temperatures.

There are many complexities involved in the mathematical modeling of thermal transient at the dome of missile. Various factors affect the skin temperature and they are not all equally important. Some of the factors affecting the temperature of the skin of the missile are: Heat transfer due to forced convection; External radiation from the skin and atmospheric radiation to the skin; Conduction along the skin; Solar radiation to the skin; Near-field radiation from hot gases, such as the hot gas cap around the nose of the missile; Internal radiation to and from the skin; Conduction through the skin; Internal convection from the skin; Forced cooling or heating. In this work, the project of the optical system the influence of the parameters Solar radiation to the skin, Near-field radiation from hot gases, Internal radiation to and from the skin, Internal convection from the skin; Forced cooling or heating was considered implicitly by the use of PSI method.

2.1.1. Heat transfer due to forced convection.

In the absence of any internal cooling or heating process, forced convection is the most significant factor involved in the heating analysis of a high-speed missile. Areas near to the stagnation point, derive most of their heat from the compression of the air. These regions of the missile will not have a large variation of temperature normal to the surface. This also means that there is a large supply of heat energy, so that any conduction of heat away from the skin will be quickly replenished. It is likely that in this region the flow will be laminar, especially for an IR missile where the sapphire dome is very smooth. This will affect the ability of the boundary layer to transfer heat energy to the missile surface; a laminar boundary layer will conduct less heat than a turbulent one. For a supersonic missile, the stagnation temperature is strongly dependent on the Mach number. The stagnation temperature (T_0) is a function of the free-stream temperature ($T_{\inf}$) and Mach number ($M_{\inf}$) only:

$$\frac{T_0}{T_{inf}} = 1 + \frac{\gamma - 1}{2} M_{inf}^2 , \tag{2}$$

Areas on the missile far away from the stagnation point will derive most of their heating from the viscous deceleration of the air in the boundary layer. For a high-speed boundary layer, the air is brought to rest at the wall in a thermodynamically irreversible process. Part of the kinetic energy is converted to heat and part is dissipated as viscous work. The boundary layer is very thin in comparison to the missile and there can be a large temperature gradient in the boundary layer, especially at the larger Mach numbers. The thin nature of this boundary layer implies that there is little heat generation capacity and as a result, the amount of heat energy conducted away from the boundary layer will strongly affect the temperature at the surface of the missile. The variable that can be used to estimate the influence of these parameters on the flight conditions is the recovery temperature. The recovery temperature is a function of the nearby temperature and Mach number just outside of the boundary layer, and it is dependant of the type of boundary layer. The recovery temperature is higher for a turbulent boundary layer. The recovery temperature (T_{wr}) at each flight condition is obtained from the trajectory profile for the baseline model of the missile. Given this data, the following equation is solved to determine the ratio between the recovery temperature and the stagnation temperature (T_0) at the boundary layer edge:

$$\frac{T_{wr}}{T_0} = r + \frac{1 - r}{1 + \frac{\gamma - 1}{2} M_1^2} , \tag{3}$$

Where r is defined for laminar flows as:

$$r = \sqrt{\Pr} , \tag{4}$$

and defined for turbulent flows as:

$$r = \sqrt[3]{\Pr} . \tag{5}$$

The subscript 1 is related to the edge of boundary layer.

2.1.2. External radiation from the skin and atmospheric radiation to the skin

At supersonic speeds, the missile skin temperature can achieve high enough temperatures that the radiation from the skin needs to be taken into account. When the surface temperature is elevated, it will lose heat to its surroundings. It is relatively easy to calculate this loss of heat energy using the Stefan-Boltzmann equation:

$$q_{rad} = \alpha \varepsilon_{air} B T_{inf}^4 - \varepsilon B T_{we}^4 . \tag{6}$$

where α is the normal total surface absorvity, ε is the normal total surface emissivity, B is Stefan-Boltzmann radiation constant and T_{we} is the wall equilibrium temperature.

2.1.3. Near-field radiation from hot gasses, such as the hot gas cap around the nose of the missile

This can be of particular concern for an IR missile where the optical window is directly behind the hot gas cap formed by the detached shock wave. For the purpose of this study this contribution is ignored as it will unlikely affect the surface temperature significantly, especially since the dome is transparent. However, this will obviously affect the sensitivity of the Infra Red detector and would be an area for further investigation.

2.1.4. Local surface Mach number and temperature

Pressure distributions for the missile airframe can be calculated using inviscid Euler calculations. In this work these were performed for the axi-symmetric case, i.e. zero-incidence since it is the more conservative condition. These pressure data are non-dimensionalised to allow the extension to free stream conditions other than those for which they were calculated. The usual non-dimensional formulation, or pressure coefficient, is given below.

$$Cp_x = \frac{p_x - p_{\inf}}{p_{dyn}}, \tag{7}$$

where p_x is the pressure at the dome surface, $p_{\inf}$ is free stream pressure and p_{dyn} is the dynamic pressure observed during the flight. However, an alternative formulation is chosen because it gives a better match to the actual pressure profile when different free-stream conditions are applied. The data are presented below as a ratio of the local static pressure to the stagnation pressure (P_0) at the nose.

$$Cp_x = \frac{p_x}{P_0}. \tag{8}$$

The stagnation pressure can be calculated for subsonic flow using the isentropic assumption. For supersonic flow, with a detached bow shock, the total pressure drop through the shock needs to be taken into account. For real viscous flow over a missile body, with heat transfer, the local Mach number (M_1) and temperature at the edge of the boundary layer (subscript 1) can be approximated by using the inviscid isentropic calculations for the values at the surface. For isentropic inviscid flow the relationship between the local Mach number and static pressure is given by the following equation, ESDU item 82018.

$$M_1 = \sqrt{\frac{2}{\gamma - 1}\left[Cp_x - \frac{\gamma - 1}{\gamma}\right]}. \tag{9}$$

For isentropic inviscid flow with no heat transfer to or from the surface the local surface temperature is given by the following equation, ESDU item 82018.

$$T_1 = T_{\inf}\left(Cp_x \frac{\gamma - 1}{\gamma}\right)\left(1 + \frac{\gamma - 1}{2} M_{\inf}^2\right). \tag{10}$$

2.2 Heat Balance

The heat balance equation can be written as Eq (11). For steady state conditions, the right-hand-side of the above equation is zero. This is called the equilibrium temperature. To perform a transient calculation the above equation is used for each time step and the surface temperature is updated accordingly.

$$\dot{q}_{conduction} + \dot{q}_{convective} + \dot{q}_{radiation} = c\rho e \frac{\delta T_{we}}{\delta t}. \tag{11}$$

where c is the specific heat capacity, ρ is a density of material, e is the thickness and t is the time.

2.2.1. Conduction

For heat transfer through a thin skin the following calculation can be used.

$$\dot{q}_{conduction} = k \frac{T_{air\_inside} - T_{we}}{\Delta t}. \tag{12}$$

where k is thermal conductivity and T_{air_inside} is the temperature of air inside the dome. Heat transfer along a thin skin can be included by solving for the differential heat flux. The following calculation can be used to include this effect. For the purpose of this analysis, multiple iterations of this equation are performed for each time step.

$$\dot{q}_{conduction}^{skin} = k \frac{\delta t}{\delta x}\frac{\delta T_{down}}{\delta x} - k \frac{\delta t}{\delta x}\frac{\delta T_{up}}{\delta x}. \tag{13}$$

Here the temperature difference downstream is defined as δT_{down} and the temperature difference upstream is defined as δT_{up}. The term $\frac{\delta t}{\delta x}$ is used to scale the heat flux per m^2 along the skin to the same scaling as the heat flux through the skin surface.

2.2.2. Forced Convection

The convective heat transfer is defined as being the Stanton number times the total potential heating rate. The total potential heating rate can be calculated as the total heat energy available.

$$\dot{q}_{\max} = \rho V c_p \left(T_{wr} - T_{we}\right). \tag{14}$$

So the convective heat flux is calculated using the Stanton number (St), the value of which is dependant on the type of boundary layer in existence.

$$\dot{q}_{convection} = St \ \dot{q}_{\max} . \tag{15}$$

For the purpose of this study, it is assumed that the sapphire dome section of the nose will experience laminar flow and down stream of the dome-nose interface step will be turbulent. The smooth surface of the dome should allow for laminar flow up to a reasonably high Reynolds number while the step in the nose will likely trigger a turbulent boundary layer down stream. For the laminar dome section it is assumed that all of the flow ingested into the boundary layer is processed by the near-normal portion of the bow shock. Thus, the local properties are computed using the known stagnation point conditions. Kays's (Mendenhall, 2000) expression is used for calculating the Stanton number for the laminar dome section, which is:

$$St = \frac{0.33}{\Pr^{\frac{2}{3}} \sqrt{\mathrm{Re}}} \left(\frac{T_1}{T_{wr}}\right)^{0.12} \left(\frac{T_{wr}}{T_{we}}\right)^{0.08}, \tag{16}$$

where Re is the Reynolds number and $\Pr$ is Prandtl number. For the turbulent downstream section, the expression developed by Vaglio-Laurin (Mendenhall, 2000) is used for calculating the Stanton number:

$$St = \left(\frac{0.0296}{\Pr^{\frac{2}{3}} \mathrm{Re}^{0.2}}\right)^{\frac{\mu_1}{\mu_0}}, \tag{17}$$

where μ is the viscosity and the subscript 0 is related to the stagnation conditions.

2.2.3. Internal temperature

The mathematical formulation for the determination of temperature inside of missile front section is based on "lumped parameters" method and experimental data. In this work, the main objective is to generate a range of possible thermal solicitations that the optical system must support. It is not aim to define, exactly, the temperature of dome and optical components. In this context, the formulation "lumped parameters" is more practical when compared to the finite element, for example, since many flight profiles must be tested. So, it was considered the following thermal "components": (1) Time variation of experimental temperature at the node A (Fig. 2); (2) Conduction Resistance (R_k): between the components of optical system; (3) Free convection (R_{hf}): between air inside of dome and optical components. Should be note that this formulation use results from experimental test to estimate the loss heat from the system in carriage flight. Based on this formulation, it can be estimated the temperature of optical components, since:

$$\frac{dT_i}{dt} = \frac{\left(\dot{q}_{hs} - \dot{q}_k^i\right) S_{op}^i}{C_{op}^i} . \tag{18}$$

where C_{op}^{i} is the thermal capacity of air inside of dome and the superscript "i" is related to the optical component; S_{op}^{i} is the wet area of dome and optical components. The heat flux $\dot{q}_{hs}$ is the convective flux from the skin to the optical system environment. The parameter $\dot{q}_{k}^{i}$ is the heat flux by conduction among the optical components.

2.3. Numerical Implementation

Essentially, the algorithm applied to solve the mathematical model developed for aerodynamic heating of dome of a supersonic missile is based on the PSI method. The steps involved in this process are shown bellow:

1- Input:

Initial conditions in term of temperature and the initial guess for heat flux $\dot{q}_{hs}$, Eq. (18) ;
Geometry of dome indicating the laminar and turbulent regions;
Physical properties of missile front section (dome and optical system);
Pressure distribution on the dome (CFD results);
Flight profile from the flight dynamics (carriage flight);
Temporal variation of experimental temperature (T_{exp}) at the contact point A, Fig. (2).

Marching Time …

2- Calculate local Mach number (M_1) at edge of boundary layer based on the flight profile- Eq. (9);

3- Calculate stagnation temperature (T_0) during the flight – Eq. (2);

4- Calculate recovery temperature (T_{wr}) in all regions on the dome – Eq. (3);

5- Determine the wall equilibrium temperature (T_{we}) and the temperatures T_i at the internal components of the optical system from the system of equations 6, 11, 12, 13, 14, 15, 16, 17 and 19 using a estimate value for heat flux $\dot{q}_{hs}$. Note that one of T_i is the temperature at the node A, which is, $T_{i=A}$;

6- With $\dot{q}_{hs}$ and T_i it is possible to estimate the value for the temperature of air inside of dome (T_{air_inside});

7- Go to the step 2;

End of Marching Time.

8- Compare the experimental temperature at the node A with the results from the Marching time, which is, $T_{i=A}$;

9- If $Cost = Abs\left(T_{i=A} - T_{i=A}^{Exp}\right) > 10^{-04}$, adopt another value for $\dot{q}_{hs}$ using a optimization algorithm and go to the marching time (step 2);

10- The method converge when the cost function is smaller than 10^{-04} .

11- Output

The wall equilibrium temperature (T_{we});
The temperatures T_i at the internal components of the optical system;
The temperature of air inside of dome (T_{air_inside});
The average heat flux $\dot{q}_{hs}$ inside of dome;

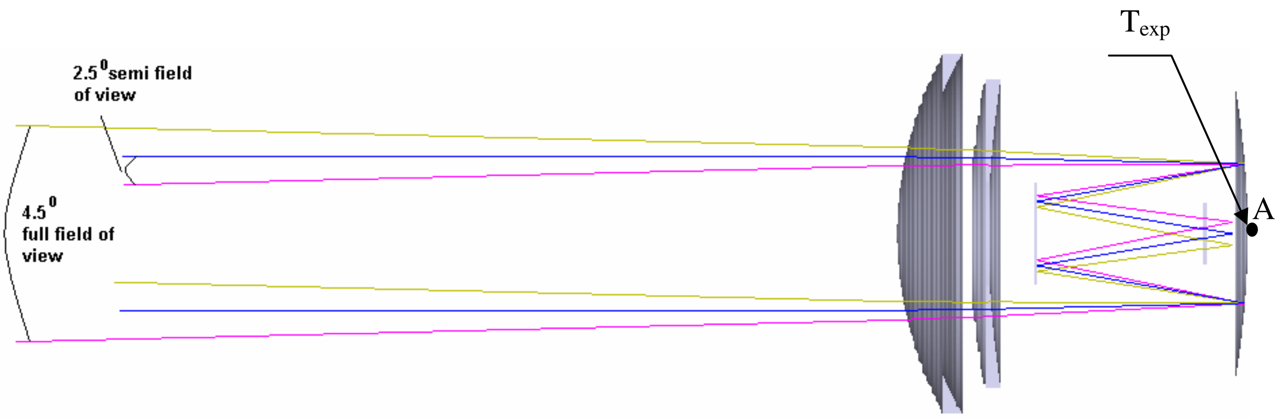

Figure 2 – Geometric scheme of the optical system

3. Results

3.1. Flight Profile

In aircraft close-in-combat scenarios the ability to engage targets in the rear hemisphere, is a significant advantage. Super-agility in missiles refers to this capability. Following a successful missile launch and separation, dynamic pressures are often too low for aerodynamic controls to make a quick turn. When the propulsion system ignites, vectoring the thrust (or using reaction jets) can provide this capability, and as the velocity increases, the aerodynamic surfaces become more effective. For the missile to possess super-agility (high-angle-of- attack capability) some form of alternate control is needed. Figure 4 illustrates the maneuvering of an agile missile from launch to endgame, indicating a high-angle-of-attack (AOA) maneuvering capability provided by either thrust vector control (TVC) or reaction control system (RCS) thrusters (Wise and Roy, 1998), Figure 3. From the requirements of system, it was defined one critical profile of flight related to the maximum carriage flight profile (M_{inf} =1.2) in order to evaluate the optical system design.

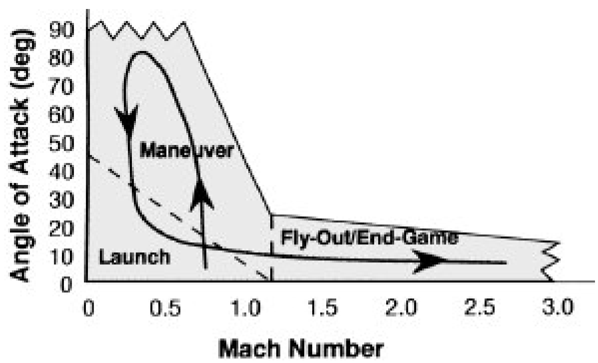

Figure 3 – Agile missile flight envelope (Wise and Roy, 1998)

3.2 Range of Temperature for Optical System Analysis

Figure 4 shows the thermodynamic parameters used in the aero thermal simulation. The atmosphere model is described by ISA model (block set of SIMULINK®). The physical properties and geometrical configuration of dome are defined by thermal conductivity = 140W/m/Kradio = 75 mm; thickness ≅ 2.5 mm, respectively.

The maximum temperature obtained for optical system from the critical flight conditions was 85.4°C. The design of optical system will utilize the maximum free flight temperature profile as set forth in the specification discussed above.

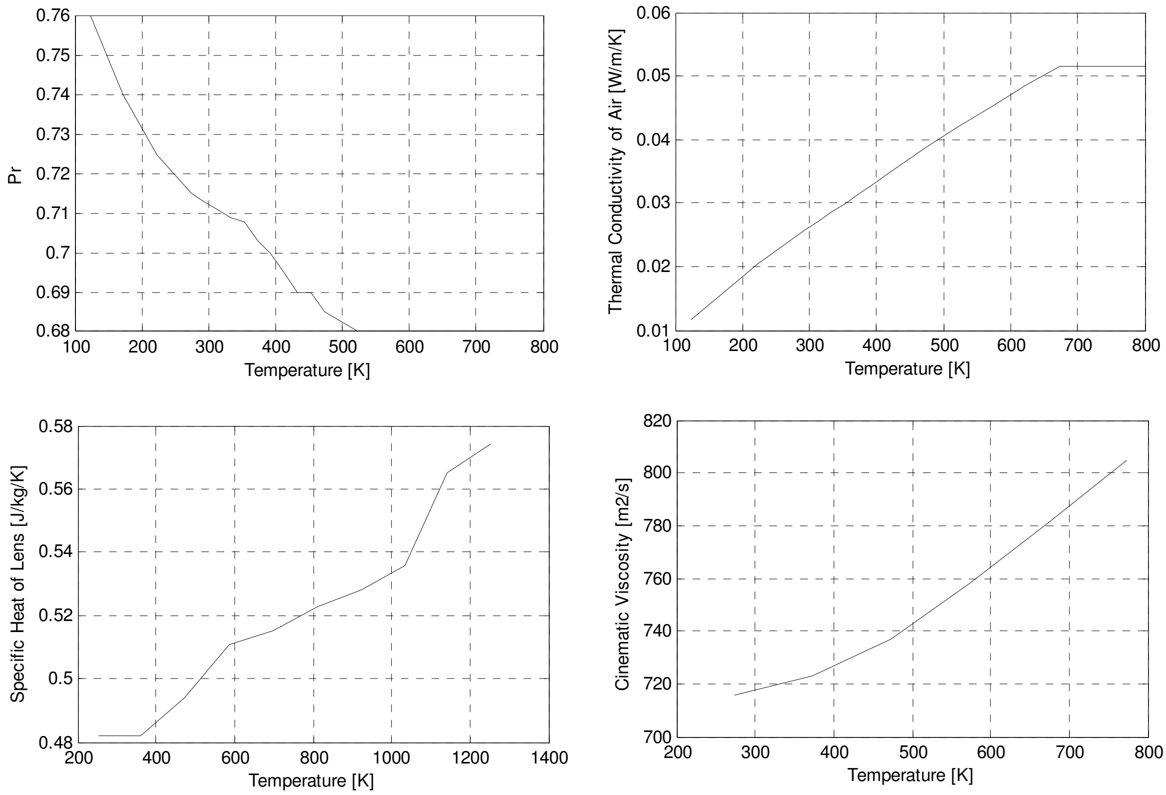

Figure 4 – Thermodynamic properties

3.2 Requirements for Optical System

Table 1 shows the main requirements for the optical system proposed by this work. It is interesting to note that the range of temperature had been obtained based on precedent thermal analysis, Leite Jr and Silva (2007).

Table 1 – Requirements for optical system

Requirement	Values	Requirement	Values
Wavelength	3,8μm – 5,0 μm	Energy focused on detector	≥80% over full field of view
Field of view	3.0^0	Image size (detector size)	Square array: 7.2mm width
Dome diameter	150 mm	Dome operational temperature	- 40 C° to 300 C°
F-number	1.92166	Optical operational temperature	- 40 C° to 83 C°
Axial color distance	≤ 40μm	Entrance pupil diameter	> 71 mm

3.3 Sonic Line

The near-field radiation from the hot gas cap at the nose is not considered in this analysis, since it is unlikely to affect the surface temperature significantly (especially since the dome is transparent). However, this will obviously affect the sensitivity of the Infra Red detector. This is an area for further investigation and will not be discussed further here. Figure 5 has been included for reference purposes. Here the change in size of the area of high temperature gas behind the shock wave is shown as a function of increasing flight speed. The red line in the Mach 0.9 case shows an area of supersonic flow, while the blue lines in the other cases show areas of subsonic flow.

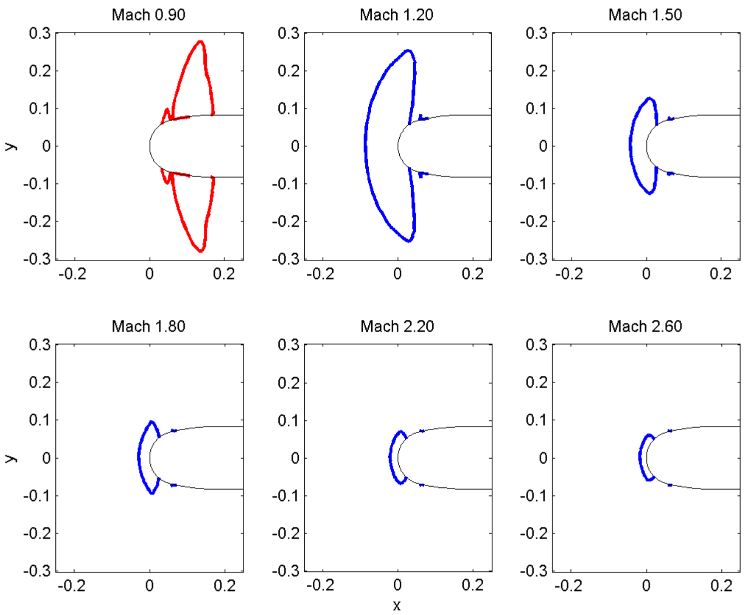

Figure 5 – Sonic Line

3.4 Optimum Optical Design

Figure 6 shows the flow diagram of the optimization process developed to design of the system. After the definition of requirements, a first optical approach was designed. Then, a thermal sheet configuration and a merit optimization function are defined and the optimization routine starts to run. After some interactions, the value of the merit function will stabilize because the system has found a minimum for its value. If the system is accomplishing the requirements, the system is frozen and the results are collected. If the system is not good enough, the requirements are relaxed and the routine runs again. If no system could be found, it is necessary to choose a new design, with new materials and shape for all elements, including thickness and radius of curvature.

Fig. 7 illustrates the worst case obtained from the optimization process. It is a strong degeneration in the center of the image, with an energy level lower than 73%. This extreme condition, it might be a threat, to the performance of the missile, such an energy level. If it is considered that the missile will stay in this condition for longer that 2 or 3 seconds, it means that the target will be lost. However, since only in the center there is degradation and in the rest of the detector the energy focused on it is above 80% it is possible to redesign the interface components (contact resistance) in order to choose the best material in terms of physical dilatation to compensate this degradation.

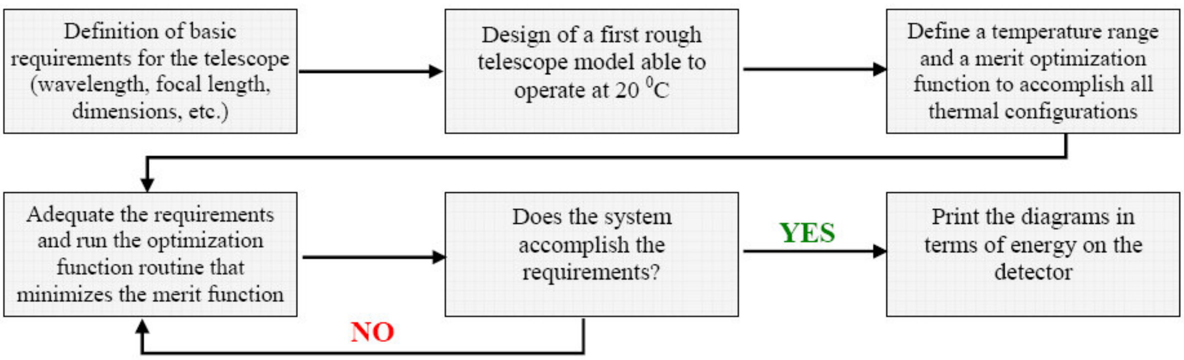

Figure 6 – Flow diagram for optimization, Leite Jr and Silva (2007)

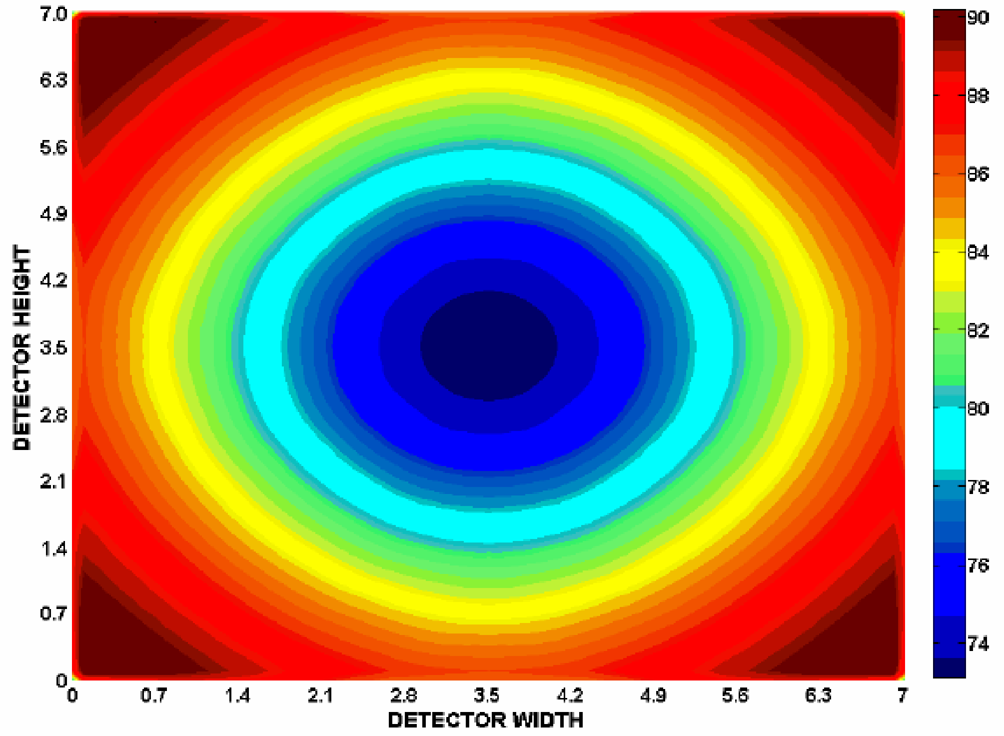

Figure 7: System at 86°C and dome at 300°C

4. Conclusion

The influence of the aerodynamic heating for a missile dome flying at supersonic speed is evaluated in respect to optical performance. This aerodynamic heating is defined as the rise in temperature of the air adjacent to the external surface of a missile due to compression and friction. At high speeds, the external temperature of the missile can affect the design of the missile system and introduce problems with regard to the insulation of certain sub-systems. While it appears relatively easy to calculate the aerodynamic heating due to compression and friction the actual wall temperature attained is more difficult problem, and most likely a transient one. Further factors need to be included when attempting to estimate the skin temperature of a supersonic missile; these include factors such as radiation and conduction. This study looks at the interaction of these various factors and their application to the missile heating problem using a mixed of classical relations provided in the literature to this type of problem, Computation Fluid Dynamic (CFD) techniques and experimental data. The finite difference method is then used to solve the resulting equations and the temperature distributions at the dome and inside it are obtained. Using the dome internal temperature distribution, the performance degradation of the optical system is estimated in terms of the energy focused on the detector. Using the software for optical simulations named ZEMAX, the system is designed to suit the temperature range in order to achieve the specified performance. This method is sufficiently accurate and fast to allow extensive analysis of flight profiles. This should allow the identification of potential problem points in the flight profile that can then be further analysed in more detail with a more accurate method. Further expansion of this method could include a finite element model of the internal structure. This would allow a more detailed analysis of the heating problems experienced by the missile sub-systems. Finally, it is important to have in mind that a tolerance analyze to the optical system is fundamental, due to precision assemble limits and lens quality. Since the distance between elements and even the curvature radii, as well as the aspheric constants, are essential parameters to the project, it is very important to know their manufacturing tolerances.

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