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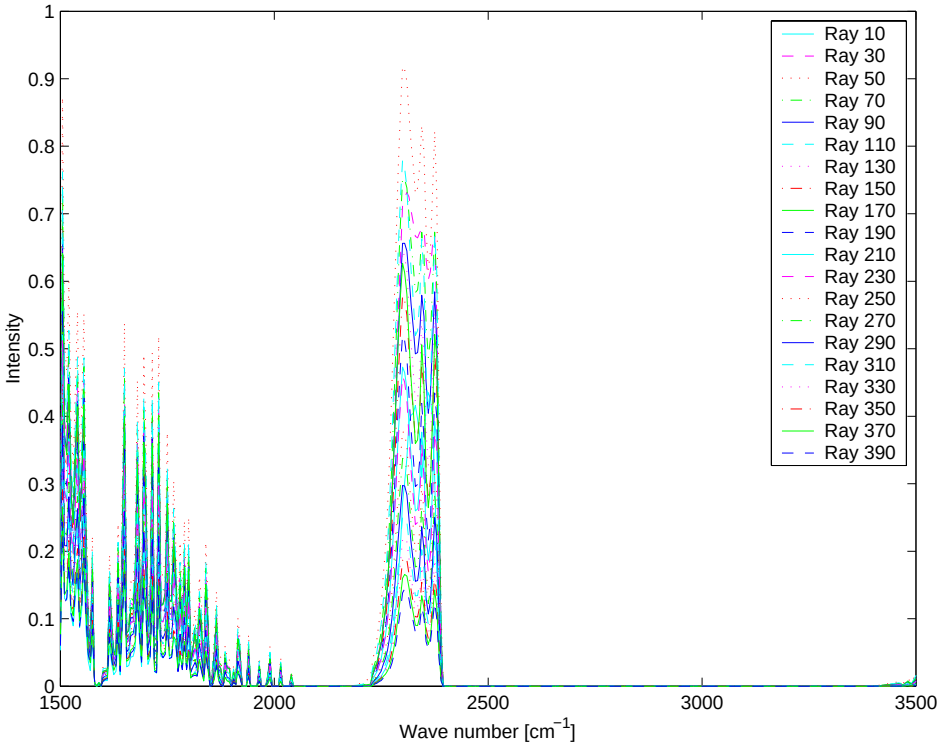
Marlene Andersson

Derivation of Equations used by the Computer Program SIGGE for Calculating IR-intensity



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Abstract

To be able to predict the IR-signature of an aircraft for example, the heat radiated, in form of IR-radiation, from the aircraft has to be calculated.

The module based code SIGGE, for calculating the IR-signature, is under development. This code uses a number of equations to calculate the IR-intensity.

This report describes how these equations are derived together with a brief discussion about radiative heat transfer.

Contents

List of Symbols

A	area	[m^2]
b	black body	
c	speed of light	[m/s]
c_0	speed of light in vacuum	2.9979×10^8 m/s
h	Planck's constant	6.6261×10^{-34} Js
I	intensity	[W/sr]
I_η	spectral intensity	[W/sr/cm^{-1}]
k	Boltzmann constant	1.3807×10^{-23} J/K
L	radiance	[W/sr/m^2]
L_η	spectral radiance	[W/sr/cm^{-1}/m^2]
n	refractive index	[-]
p	pressure	[Pa]
s	length	[m]
sp	species	
t	length	[m]
T	temperature	[K]
TP	target position	
VP	view position	
α	absorptivity	[-]
α_η	spectral absorptivity	[-]
ε	emissivity	[-]
ε_η	spectral emissivity	[-]
η	wave number	[cm^{-1}]
θ	angle	[rad]
κ_η	absorption coefficient	[cm^{-1}]
κ_η^{sp}	absorption coefficient of species	[cm^{-1}]
$\kappa_{\rho\eta}$	mass absorption coefficient	[cm^{-1} m^3/kg]
$\kappa_{p\eta}$	pressure absorption coefficient	[cm^{-1}/Pa]
λ	wave length	[μm]
ν	frequency	[Hz]
ρ	density	[kg/m^3]
τ	transmissivity	[-]
τ_η	spectral transmissivity	[-]
Φ	radiative flux (power)	[W]
ϕ	angle	[rad]
Ω	solid angle	[sr]
ω	angular frequency	[rad/s]

1 Introduction

Radiative heat transfer in the infrared (IR) interval is normally defined as electromagnetic waves or electromagnetic radiation with wavelengths between 0.7 μm and 100 μm, see Figure 1. Electromagnetic waves could be represented by wavelength, λ, frequency, ν, wave number, η, or angular frequency, ω. They are related to one another by:

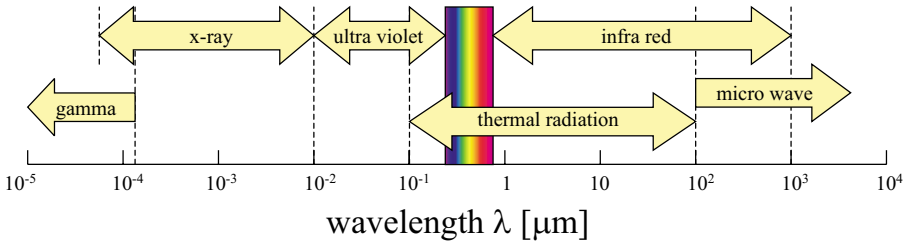


Figure 1. Spectrum for electromagnetic radiation.

$$\nu = \frac{\omega}{2\pi} = \frac{c}{\lambda} = c\eta \tag{1}$$

where $c = \frac{c_0}{n}$ is the speed of light in a medium with refractive index n and c_0 is the speed of light in vacuum. In the IR-region, the wavelength or the wave number are the most common used with the units μm for wavelength and cm^{-1} for wave number. In Table 1, some relations between wavelength and wave number are presented.

Table 1. Relations between wavelength and wave number.

Wavelength [μm]	Wave number [cm^{-1}]
0.7	$\sim$ 14000
3	$\sim$ 3000
14	$\sim$ 700

In room temperature, the largest part of the IR-radiation is in the interval 0.7 - 14 μm. In the atmosphere, the transmission is largest between 3 - 5 μm and between 8 - 14 μm. In the interval in between, a large part of the IR-radiation is absorbed.

A surface or a body, with a temperature T $>$ 0 K, radiates heat in form of IR-radiation. The intensity is dependent on the structure and temperature of the surface. In a gas, the IR-radiation heat transfer depends on the composition of the gas and gas temperature.

Different vehicles will emit IR-radiation of different wavelength and intensity, this will give rise to an IR-signature. For an airborne vehicle, the hot plume from the engine will contribute largely to the IR-signature. For some military vehicles, it is of most importance to have a low IR-signature.

By doing calculations of the IR-signature for an aircraft or parts of an aircraft, the factors that contribute the most and critical points can be identified and minimised.

The Department of Computational Aerodynamics, Aeronautics Division (FFA), at the Swedish Defence Research Agency (FOI), is currently developing a computer code, SIGGE, for calculation the intensity of IR-radiation from airborne vehicles or specific parts of these vehicles.

In this report, the equations used for intensity calculations, on which some parts of SIGGE are based, are described. In section 2, the basic layout of program itself is described. Some general concepts in radiative heat transfer is found in section 3. In section 4 and section 5 are the data base with absorption coefficients and the distribution of species discussed. In section 6, the definition of cells is presented. The intensity and the radiance is discussed in section 8. Radiation from walls are treated in section 7. The resulting final equation is found in section 9. Some ways of presenting the resulting intensity are discussed in section 10. In section 11, conclusions and outlook are found.

2 Basic layout of SIGGE

Parameters needed for the IR-calculation, in a gas, are for example temperature, pressure and distribution of the different species. The values of these parameters can be extracted from CFD-calculations[1]. When performing a CFD-calculation, the object of interest is surrounded by a mesh and a solution of the fluid dynamics equations is found, defining flow quantities in each cell. Thus, for each cell in the mesh, the parameters of interest, for the IR-calculation, are known.

The proposed structure of SIGGE is presented in Figure 2. The code is module

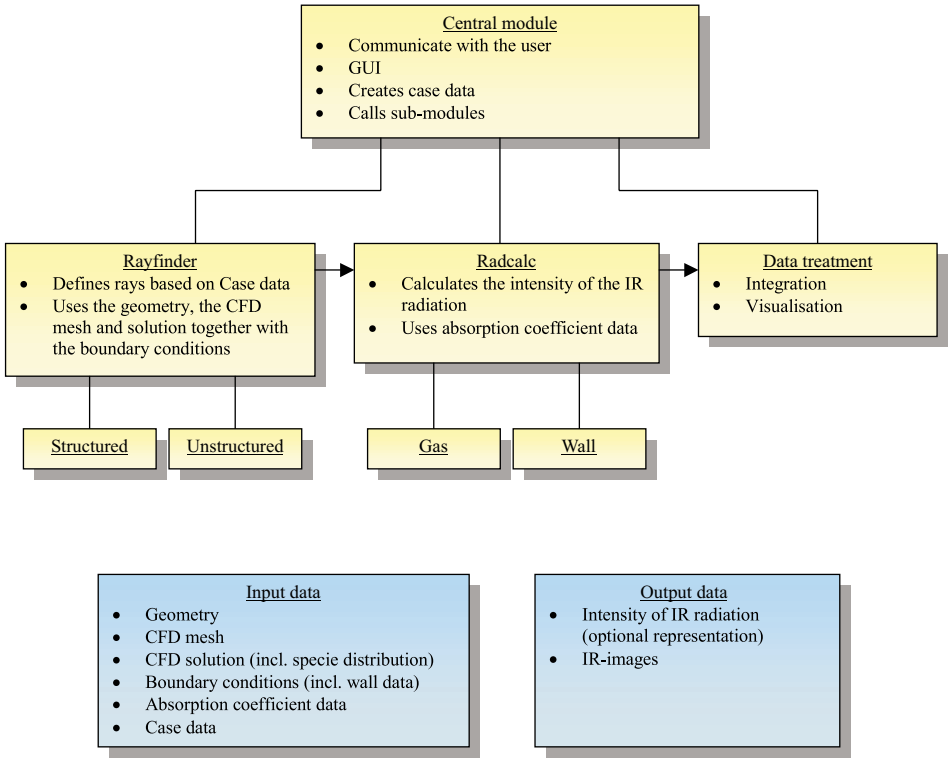


Figure 2. The proposed structure of the module based code SIGGE.

based, where each module can operate alone or together with other modules. The modules discussed in this report are RAYFINDER and RADCALC.

The user will define an imaginary sensor, which consists of a flat plane with a number of pixels, giving an IR-image for each specified wave number, see Figure 3. The orientation of the sensor in space is defined by two orthogonal vectors, $\hat{\theta}$ and $\hat{\phi}$. Each pixel has a field-of-view of $\Delta\theta \times \Delta\phi$, which gives a total field-of-view of $n_\theta \Delta\theta$ and $n_\phi \Delta\phi$, where n_θ and n_ϕ are the number of pixels in the $\hat{\theta}$- and $\hat{\phi}$-directions, respectively.

The user will define a view position, which is the position where the imaginary sensor is located, and a target position, which is the position in space where the centre of the sensor is aiming at, giving an aiming direction, which should be orthogonal to the sensor plane.

The module RAYFINDER will use this information to draw rays from the view position through the mesh. Each ray will be separated from their neighbours with angles of $\Delta\theta$ and $\Delta\phi$. Thus, each ray will correspond to a pixel in the imaginary sensor. In Figure 4, a view position and a target position are defined

[1] CFD: Computational Fluid Dynamics

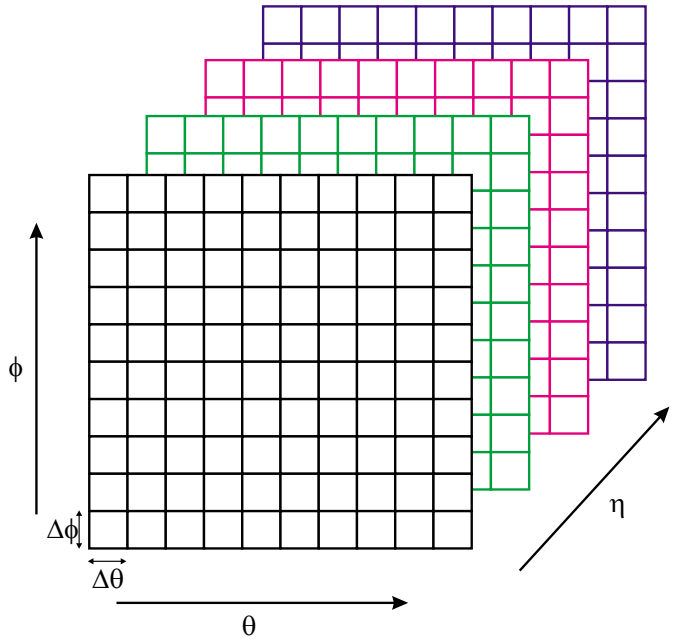


Figure 3. Imaginary sensor defined by the user. The sensor will collect one image for each wave number, η, specified. Each pixel has the field-of-view: $\Delta\theta \times \Delta\phi$.

in space, making, in this case, the aiming direction of the sensor run along the z-axis. The imaginary sensor will, therefore, coincide with the x-y plane and the $\hat{\theta}$-direction can be chosen to run along the x-axis and, consistently, the $\hat{\phi}$-direction will run along the y-axis.

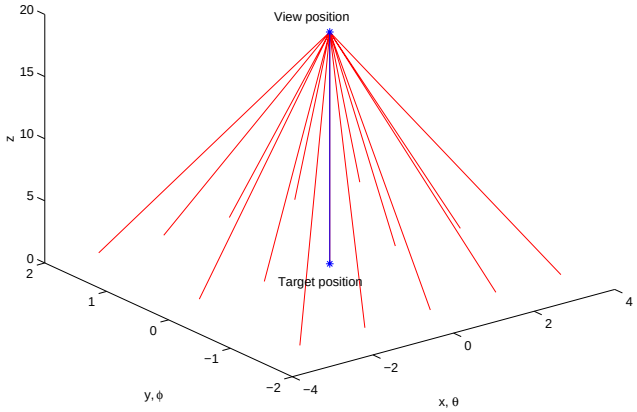


Figure 4. Rays are drawn from a view position where the centre-ray is drawn toward the target position. Each ray is separated from the neighbouring rays with angles of $\Delta\theta$ and $\Delta\phi$.

The user will define the number of rays, $n_\theta \times n_\phi$, and the angular resolution, $\Delta\theta \times \Delta\phi$. The method of drawing rays through a mesh, see Figure 5, is called the line-of-sight method. It is of great importance to point out that the normal spherical coordinates are not used here.

The radiative heat transfer, which gives the IR-intensity, is calculated along each ray giving a one-dimensional problem. This is discussed in more detail in section 6. The module RADCALC will do the actual calculation and it uses a data base of absorption coefficients and the parameters given by the CFD-solution.

The gas, through which the rays are drawn, can be composed of different species, such as CO_2 and H_2O. All species have specific absorption coefficients,

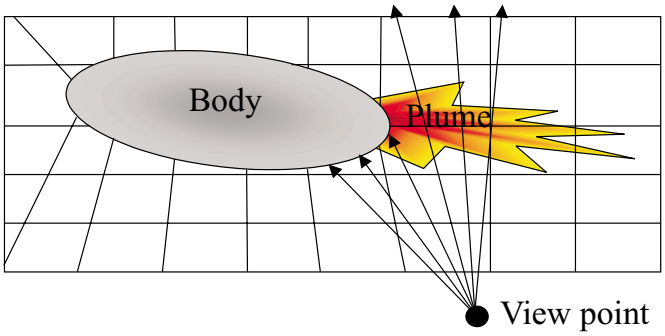


Figure 5. Rays are drawn from a view position toward an object in space or “infinity” through a mesh.

for different wave numbers, given in the data base, see section 4.

For a more detailed description of the program code SIGGE, Ref. [1] is recommended.

3 General concepts in radiative heat transfer

For gases and surfaces, we define the absorptivity, α, the transmissivity, τ, and the emissivity, ε:

$$\textit{Absorptivity: } \alpha = \frac{\text{absorbed part of incoming radiation}}{\text{total incoming radiation}} \tag{2}$$

$$\textit{Transmissivity: } \tau = \frac{\text{transmitted part of incoming radiation}}{\text{total incoming radiation}} \tag{3}$$

$$\textit{Emissivity: } \varepsilon = \frac{\text{energy emitted from a surface}}{\text{energy emitted from a black body surface at same temperature}} \tag{4}$$

The spectral transmissivity in a homogen isothermal gas cell can be written as:

$$\tau_\eta = e^{-\kappa_\eta s} \tag{5}$$

where s is the thickness of the gas cell and the proportionality constant κ_η is the absorption coefficient. The spectral absorptivity in the gas can be written as:

$$\alpha_\eta = 1 - \tau_\eta = 1 - e^{-\kappa_\eta s} \tag{6}$$

The spectral radiance for absorption and emission in one homogen gas cell becomes for small ds:

$$\frac{\mathrm{dL}_\eta}{\mathrm{d}s} = \kappa_\eta \left(\mathrm{L}_{b\eta} - \mathrm{L}_\eta\right) \tag{7}$$

$$\Rightarrow$$

$$\mathrm{L}_\eta = \mathrm{L}_\eta(0) e^{-\int_0^s \kappa_\eta ds} + \mathrm{L}_{b\eta}\left(1 - e^{-\int_0^s \kappa_\eta ds}\right) \tag{8}$$

$\mathrm{L}_{b\eta}$ is the spectral black body radiance given by:

$$\mathrm{L}_{b\eta} = \frac{2\pi h c_0^2 \eta^3}{\pi\left(e^{hc_0\eta/kT} - 1\right)} = \frac{C_1 \eta^3}{e^{C_2\eta/kT} - 1} \tag{9}$$

where

$$C_1 = 2hc_0^2 = 1.191 \cdot 10^{-16}\mathrm{Wm}^2 \tag{10}$$

$$C_2 = hc_0/k = 1.4388 \cdot 10^{-2}\mathrm{Km} \tag{11}$$

For further reading, Ref. [2] is recommended.

4 Data base with absorption coefficients

In the data base, the absorption coefficient, κ_η^{sp}, which is different for different species, is either given as a mass absorption coefficient, $\kappa_{\rho\eta}^{sp}$, or a pressure absorption coefficient, $\kappa_{p\eta}^{sp}$. To get the absorption coefficient, κ_η^{sp}, the partial absorption coefficient has to be be multiplied with partial pressure, p_{sp}, or partial density, ρ_{sp}:

$$\kappa_\eta^{sp} = \kappa_{p\eta}^{sp} \times p_{sp} \tag{12}$$

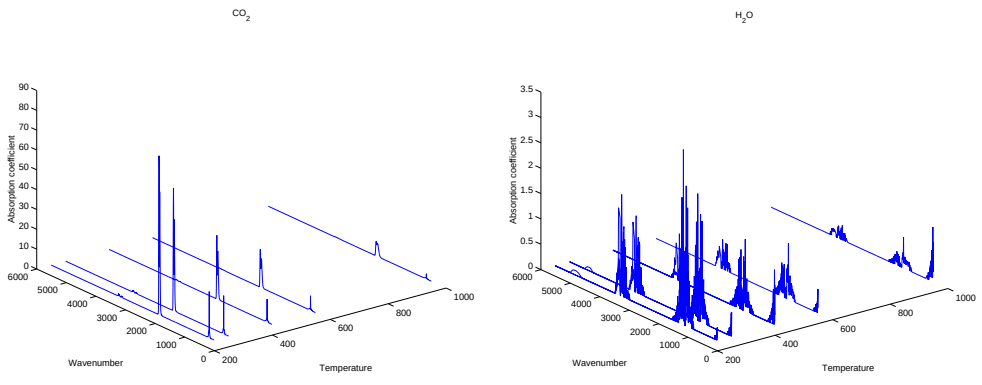
$$\kappa_\eta^{sp} = \kappa_{\rho\eta}^{sp} \times \rho_{sp} \tag{13}$$

The units of partial absorption coefficients in the data base should be $[\kappa_{\rho\eta}^{sp}]$ = $m^3 \times (kg \times cm)^{-1}$ and $[\kappa_{p\eta}^{sp}]$ = $(atm \times cm)^{-1}$, respectively. The coefficients are dependent on wave number [cm^{-1}] and temperature [K]. All species have specific absorption coefficients, which are indicated with the superscript sp, and the total absorption coefficient is achieved by adding absorption coefficients for different species:

$$\kappa_\eta = \sum_{sp} \kappa_\eta^{sp} \tag{14}$$

Pressure absorption coefficients for CO_2 and H_2O can be extracted from files generated by HITRAN and HITEMP [3, 4]. Examples of pressure absorption coefficients, with a wave-number resolution of $\Delta\eta$ = 5 cm^{-1}, are presented in Figure 6. These absorption coefficients have been extracted from HITRAN and HITEMP, by calculating a mean of the emission lines using the line strengths and Lorentz broadening [2, 3].

Figure 6. Pressure absorption coefficients, averaged over 5 cm^{-1}.



(a) CO_2 (b) H_2O

5 Mass fraction, mole fraction and distribution of species

As discussed in section 4, the partial absorption coefficients, $\kappa^{sp}_{p/\rho,\eta}$, has to be multiplied with the partial pressure, p_{sp}, or the partial density, ρ_{sp}. Thus, these quantities must be known or must be possible to calculate.

Normally, what is given in the CFD-solution is the mass fraction, which is the fraction between the ambient air and the combustion gas. The combustion gas mainly comprises N_2, O_2, H_2O and CO_2. H_2O and CO_2 will give rise to IR-signatures and thus their concentrations are needed. For simplicity, it is assumed that the ambient air will not contain species that will contribute to the IR-signature. The mole fractions for the different species in the combustion gas can, for example, be calculated with the program CET89 [5]. The mole fractions are assumed to be constant in all cells and should be given in the *input file* of SIGGE [1].

The concentration of species can be given either by the partial pressure, p_{sp}, or the partial density, ρ_{sp}, and by using the mass fraction from the CFD-solution and the mole fraction, the concentration of species could be approximated as:

$$\left\{ \begin{array}{c} p_{sp} \\ \rho_{sp} \end{array} \right\} = \textit{mass fraction for gas} \times \textit{mole fraction for species} \times \left\{ \begin{array}{c} p \\ \rho \end{array} \right\} \quad (15)$$

where p and ρ is the total pressure and density.

Doing this simplified calculation some errors will occur. When the ambient air is mixed in, the molecule weight will change, therefore, the mole fraction should be multiplied with the change in molecule weight. The mole fraction varies non-linearly with the equivalence ratio, which also will give rise to an error. These corrections are not implemented in the current version of SIGGE, therefore, the partial pressure and the partial density are impaired by a few percents error.

It should be pointed out that, if the concentration of species is given directly in the CFD-solution, SIGGE will be able to handle that as well.

6 Cell definition

The mesh around the object of interest is represented in a coordinate system. The rays drawn from the view position are represented in the same coordinate system. The coordinates of each ray are transformed to a one-dimensional system, given by t_1, $t_2 \ldots$. In Figure 7, an example, with only three cells involved, is sketched. This example will be used to illustrate and explain the equations derived in this report.

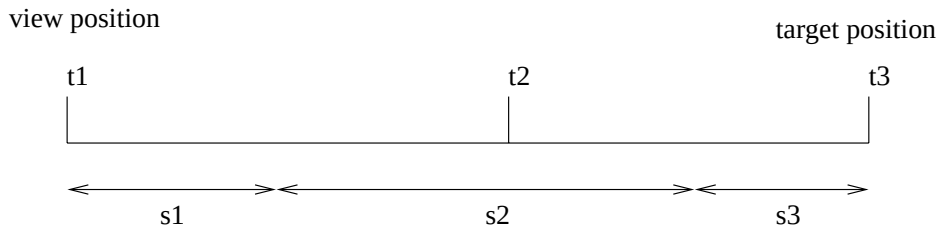


Figure 7. One example of the cell intervals. t_1 - t_3 are one-dimensional coordinates and s_1 - s_3 are the lengths of the cells.

The view position is placed in $t_1 = 0$. From the one-dimensional coordinates, the length of each cell is defined as:

$$s_1 = \frac{t_2 - t_1}{2} \tag{16}$$

$$s_2 = \frac{t_3 - t_1}{2} \tag{17}$$

$$s_3 = \frac{t_3 - t_2}{2} \tag{18}$$

Assuming that the absorption coefficient is constant through the whole cell, the radiance for each cell is given by Eq. (8) and can be written as:

$$\mathrm{L}_\eta(s_1) = \mathrm{L}^1_\eta(0)e^{-\kappa^1_\eta s_1} + \mathrm{L}^1_{b\eta}\left(1 - e^{-\kappa^1_\eta s_1}\right) \tag{19}$$

$$\mathrm{L}_\eta(s_2) = \mathrm{L}^2_\eta(0)e^{-\kappa^2_\eta s_2} + \mathrm{L}^2_{b\eta}\left(1 - e^{-\kappa^2_\eta s_2}\right) \tag{20}$$

$$\mathrm{L}_\eta(s_3) = \mathrm{L}^3_\eta(0)e^{-\kappa^3_\eta s_3} + \mathrm{L}^3_{b\eta}\left(1 - e^{-\kappa^3_\eta s_3}\right) \tag{21}$$

Assume that $\mathrm{L}^3_\eta(0) = 0$, i.e. no initial radiation from a wall nor contributions from any background outside the mesh, and that $\mathrm{L}^2_\eta(0) = \mathrm{L}_\eta(s_3)$:

$$\mathrm{L}_\eta(s_2) = \mathrm{L}^3_{b\eta}\left(1 - e^{-\kappa^3_\eta s_3}\right)e^{-\kappa^2_\eta s_2} + \mathrm{L}^2_{b\eta}\left(1 - e^{-\kappa^2_\eta s_2}\right) \tag{22}$$

Put $\mathrm{L}^1_\eta(0) = \mathrm{L}_\eta(s_2)$:

$$\begin{aligned}
\mathrm{L}_\eta(s_1) &= e^{-\kappa^1_\eta s_1}\left(\mathrm{L}^3_{b\eta}\left(1 - e^{-\kappa^3_\eta s_3}\right)e^{-\kappa^2_\eta s_2} + \mathrm{L}^2_{b\eta}\left(1 - e^{-\kappa^2_\eta s_2}\right)\right) + \\
&\quad + \mathrm{L}^1_{b\eta}\left(1 - e^{-\kappa^1_\eta s_1}\right) = \\
&= \mathrm{L}^1_{b\eta}\left(1 - e^{-\kappa^1_\eta s_1}\right) + \\
&\quad + \mathrm{L}^2_{b\eta}e^{-\kappa^1_\eta s_1}\left(1 - e^{-\kappa^2_\eta s_2}\right) + \\
&\quad + \mathrm{L}^3_{b\eta}e^{-\kappa^1_\eta s_1}e^{-\kappa^2_\eta s_2}\left(1 - e^{-\kappa^3_\eta s_3}\right)
\end{aligned} \tag{23}$$

which gives the spectral radiance in the view position, $t_1 = 0$.

7 Treatment of walls (or radiation from real surfaces)

Using the same example as in section 6, the radiance from a surface is given by:

$$\mathrm{L}_\eta = \varepsilon_\eta \mathrm{L}_{b\eta} e^{-\kappa_\eta^1 s_1} e^{-\kappa_\eta^2 s_2} e^{-\kappa_\eta^3 s_3} \tag{24}$$

where ε_η is the spectral emissivity for the wall. With direction dependence, the spectral emissivity is given by:

$$\varepsilon'_\eta(\theta) = \frac{\mathrm{L}_\eta(\hat{s}_0)\cos\theta_0 d\theta}{\mathrm{L}_{b\eta}\cos\theta_0 d\theta} = \frac{\mathrm{L}_\eta(\hat{s}_0)}{\mathrm{L}_{b\eta}} \tag{25}$$

where $\hat{s}_0$ shows the direction dependence of the radiance. Here, we are dealing with the normal spherical coordinates. The spectral hemispherical emissivity is given by:

$$\varepsilon_\eta = \frac{\int_0^{2\pi}\int_0^{\pi/2} \mathrm{L}_\eta(\theta,\phi)\cos\theta\sin\theta d\theta d\phi}{\pi \mathrm{L}_{b\eta}} \tag{26}$$

which can be written as:

$$\varepsilon_\eta = \frac{1}{\pi}\int_0^{2\pi}\int_0^{\pi/2} \varepsilon'_\eta(\theta,\phi)\cos\theta\sin\theta d\theta d\phi \tag{27}$$

For an isotropic surface, i.e. a surface that has no different structure, composition or behaviour for different direction on the surface (independent in the azimuthal angle ϕ), the spectral hemispherical emissivity is given by:

$$\varepsilon_\eta = 2\int_0^{\pi/2} \varepsilon'_\eta(\theta)\cos\theta\sin\theta d\theta \tag{28}$$

For a diffuse surface or a Lambert surface, the emissivity is the same in all directions, i.e. ε'_η is independent of θ. This gives a spectral hemispherical emissivity of:

$$\varepsilon_\eta = \varepsilon'_\eta \tag{29}$$

To conclude, to calculate IR-radiation from a surface the temperature and the emissivity of the surface have to be known.

8 Intensity and radiance

The difference between intensity and radiance can be introduced by two quotations of Boreman [6].

"Intensity, I, *has units of* W/sr *and is interpreted as power per unit solid angle."*

"Radiance, L, *has units of* W/(m^{2}sr), *and is used to characterize extended sources."*

8.1 Intensity

The radiative flux (power), Φ, is defined as [6]:

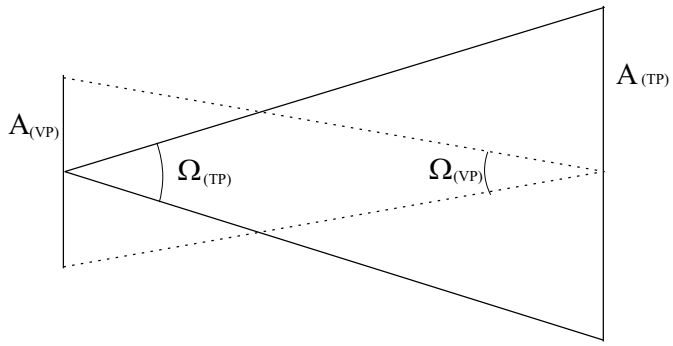
$$d\Phi = \mathrm{I} \times d\Omega_{(VP)} \tag{30}$$

or if $d\Omega \approx \Omega$:

$$\Phi = \mathrm{I} \times \Omega_{(VP)} \tag{31}$$

where Ω is the solid angle and VP is short for view position. $\Omega_{(VP)}$ is defined in Figure 8.

Figure 8. Definition of area segment and solid angles for calculating the flux.



8.2 Radiance

The radiative flux can also be defined as [6]:

$$d\Phi = \mathrm{L} \times dA_{(TP)} \times d\Omega_{(VP)} = \mathrm{L} \times d\Omega_{(TP)} \times dA_{(VP)} \tag{32}$$

where TP and VP are short for target respective view position. If $d\Omega \approx \Omega$ we get:

$$\Phi = \mathrm{L} \times A_{(TP)} \times \Omega_{(VP)} = \mathrm{L} \times \Omega_{(TP)} \times A_{(VP)} \tag{33}$$

where the area segments, A, and the solid angles, Ω, are defined in Figure 8.

Combining Eq. (31) and Eq. (33), a relation between the radiance and the intensity is accomplished:

$$\mathrm{I} = \mathrm{L} \times A_{(TP)} \tag{34}$$

9 Final equation

To calculate the intensity for the example defined in section 6, each part of Eq. (23) has to be multiplied with an area segment according to Eq. (34). Thus, the spectral intensity for a gas is given by:

$$\begin{aligned} \mathrm{I}_\eta(gas) &= \mathrm{L}^1_{b\eta}\left(1-e^{-\kappa^1_\eta s_1}\right)\mathrm{A}_1 + \\ &+\mathrm{L}^2_{b\eta}e^{-\kappa^1_\eta s_1}\left(1-e^{-\kappa^2_\eta s_2}\right)\mathrm{A}_2 + \\ &+\mathrm{L}^3_{b\eta}e^{-\kappa^1_\eta s_1}e^{-\kappa^2_\eta s_2}\left(1-e^{-\kappa^3_\eta s_3}\right)\mathrm{A}_3 \end{aligned} \tag{35}$$

The area segment is given by:

$$\mathrm{A}_i = t_i^2 \Delta\theta\Delta\phi \tag{36}$$

where t_i is defined as the distance between the ith cell and the view position, see section 6.

In the same way, the intensity from a wall, $\mathrm{I}_\eta(wall)$, is given by:

$$\mathrm{I}_\eta(wall) = \mathrm{L}_\eta(wall) \times \mathrm{A}_{(TP)} \tag{37}$$

where $\mathrm{L}_\eta(wall)$ is given in Eq. (24) and $\mathrm{A}_{(TP)}$ is the area segment at the target.

The total spectral intensity can now be written as:

$$\mathrm{I}_\eta = \mathrm{I}_\eta(gas) + \mathrm{I}_\eta(wall) = \tag{38}$$

$$\begin{aligned} &= \mathrm{L}^1_{b\eta}\left(1-e^{-\kappa^1_\eta s_1}\right)\mathrm{A}_1 + \\ &+\mathrm{L}^2_{b\eta}e^{-\kappa^1_\eta s_1}\left(1-e^{-\kappa^2_\eta s_2}\right)\mathrm{A}_2 + \\ &+\mathrm{L}^3_{b\eta}e^{-\kappa^1_\eta s_1}e^{-\kappa^2_\eta s_2}\left(1-e^{-\kappa^3_\eta s_3}\right)\mathrm{A}_3 \\ &+\varepsilon_\eta \mathrm{L}^{(wall)}_{b\eta}e^{-\kappa^1_\eta s_1}e^{-\kappa^2_\eta s_2}e^{-\kappa^3_\eta s_3}\mathrm{A}_3 \end{aligned} \tag{39}$$

since in our example $\mathrm{A}_{(TP)}$ = A_3.

10 Presenting the result

As discussed in section 2, the intensity is calculated as a one-dimensional problem for several rays. Each ray has an angular resolution in the θ- and ϕ- directions, given by $\Delta\theta$ and $\Delta\phi$. This gives rise to a pixel pattern.

The resulting intensity is calculated for each pixel or ray and the result could be presented as seen in Figure 9. The sum of all spectral intensities, giving a total

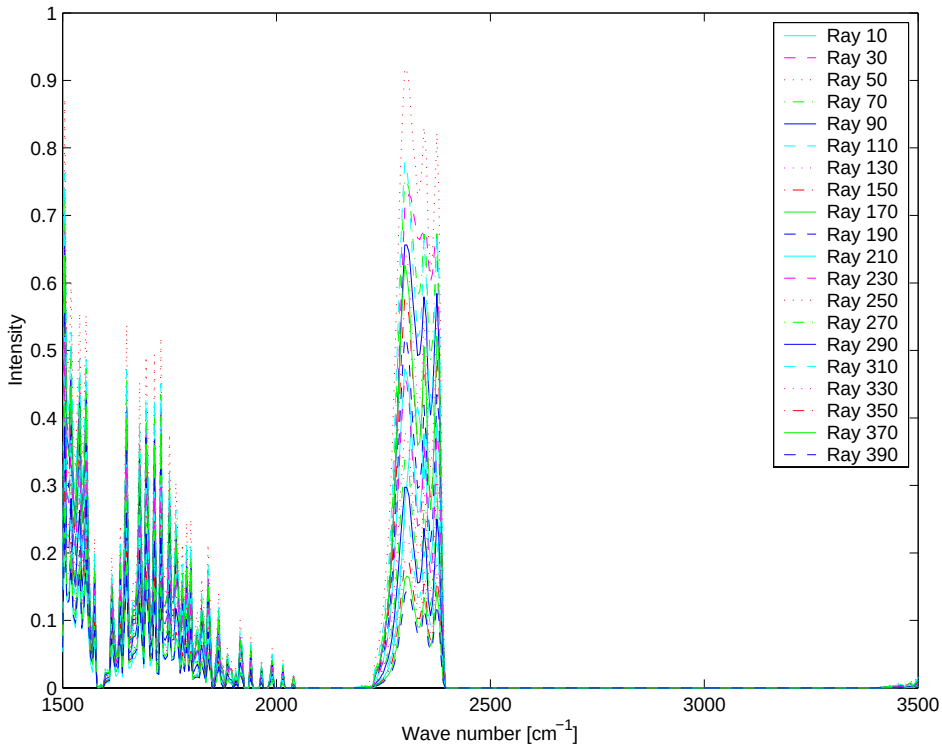


Figure 9. Example of spectra of single rays.

spectral intensity, is one other way to view the result, see Figure 10.

Yet, an other way to present the result is to integrate the intensity over all wave numbers for each ray (pixel) and present an intensity image of the target, Figure 11.

Figure 10. Example of spectrum where spectral-intensity spectra of 400 rays have been added.

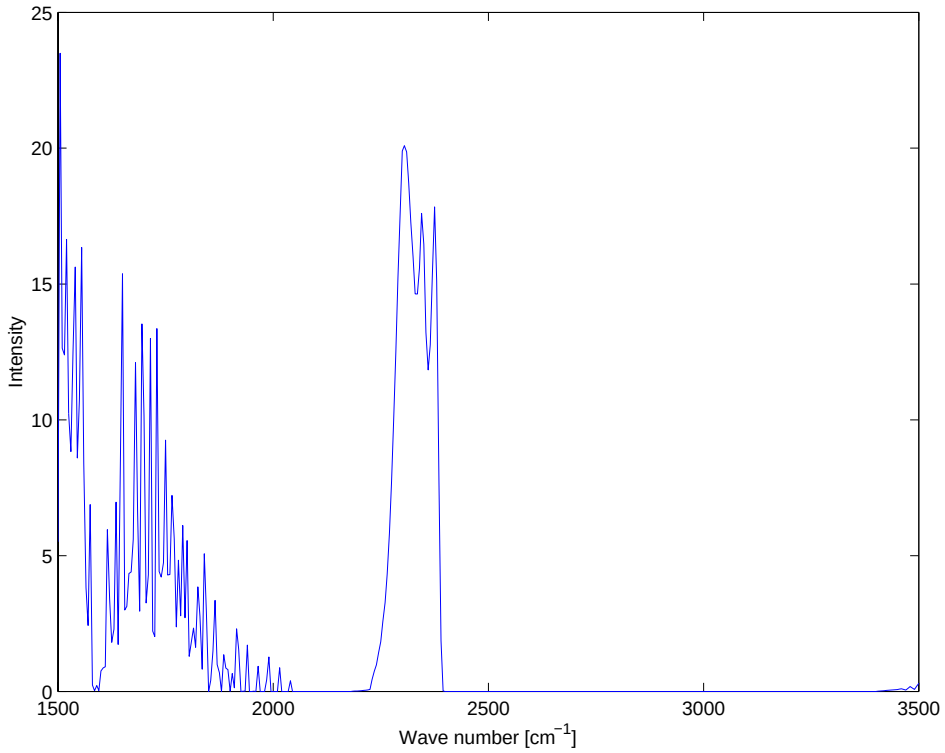
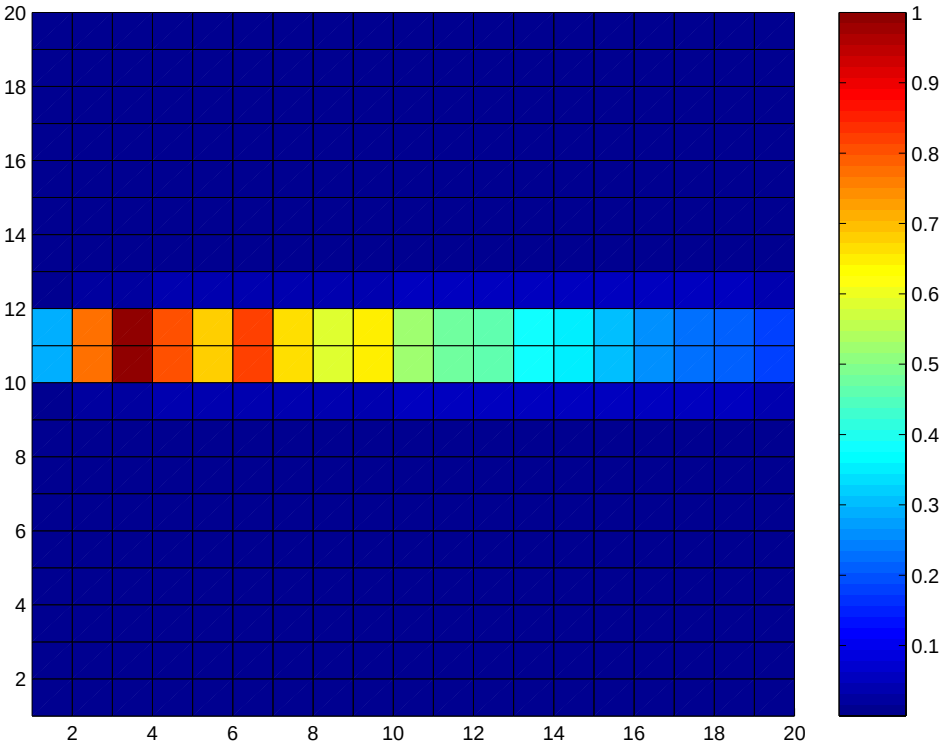


Figure 11. Example of an intensity image.



11 Conclusions and outlook

The basic layout of the module based code SIGGE, for calculating IR-intensity, has been presented. The basic equations needed for these calculations have been derived. The difference between radiance and intensity has been discussed and some ways of presenting the result have been pointed out. The treatment of walls has been discussed and equations for radiance from diffuse isotropic surfaces have been derived.

In the future, more complex equations for specific species can be added. Non-diffuse surfaces should be possible to handle as well as specular reflections, i.e bidirectional reflectance distribution functions (BRDFs) will be implemented.

An important factor in the IR-calculations are the absorption coefficients. These can be extracted in several ways, for example by considering line-by-line absorption coefficients or by statistic band models. Ways of handling this will be attended in the future.

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Report title
Derivation of Equations used by the Computer Program SIGGE for Calculating IR-intensity

Abstract

To be able to predict the IR-signature of an aircraft for example, the heat radiated, in form of IR-radiation, from the aircraft has to be calculated.

The module based code SIGGE, for calculating the IR-signature, is under development. This code uses a number of equations to calculate the IR-intensity.

This report describes how these equations are derived together with a brief discussion about radiative heat transfer.

Keywords
IR-signature, SIGGE, radiative heat transfer, flame, plume, engine

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Rapporttitel

Härledning av Ekvationer använda av Datorprogrammet SIGGE för Beräkning av IR-intensitet

Sammanfattning

För att kunna förutsäga IR-signaturen för t.ex. ett flygplan, måste värmestrålningen, i form av IR-strålning, från flygplanet beräknas.

Den modulbaserade koden SIGGE, för beräkning av IR-signatur, är under utveckling. Koden använder sig av ett antal ekvationer för att beräkna IR-intensiteten.

Den här rapporten beskriver härledningen av dessa ekvationer tillsammans med en kortfattad diskussion om värmeöverföring via strålning.

Nyckelord

IR-signatur, SIGGE, värmeöverföring via strålning, flamma, plym, motor

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