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Models of spectral radiation heat transfer for Martian space vehicles

Foreword

- **A spectral radiative heating economical computer code for space vehicles radiative gasdynamic problems is developed**
- **Radiation heating of space vehicles in complex curvilinear geometry is considered**

P_1-approximation of spherical harmonics method (SHM)

$$\frac{1}{c}\frac{\partial U}{\partial t}+\frac{1}{r}\frac{\partial rW_r}{\partial r}+\frac{\partial W_z}{\partial z}+\kappa_\nu cU=4\pi\kappa_\nu J_b,$$

$$\frac{c}{3\kappa_\nu}\frac{\partial U}{\partial r}+W_r=0,$$

$$\frac{c}{3\kappa_\nu}\frac{\partial U}{\partial z}+W_z=0,$$

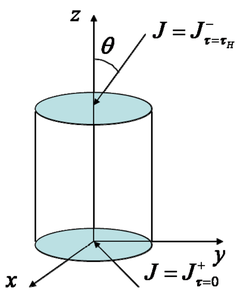
U - volume density of radiation
W - density flux
κ_ν - spectral absorption coefficient
c - light speed

Boundary conditions

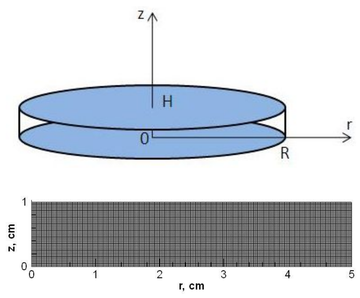
$$W\big|_{z=0}=-D\frac{dU}{dz}\bigg|_{z=0}=2\pi J_0^+-\frac{c}{2}U\big|_{z=0}$$

$$W\big|_{z=H}=-D\frac{dU}{dz}\bigg|_{z=H}=-2\pi J_0^-+\frac{c}{2}U\big|_{z=H}$$

$$J(\tau,\mu)=\frac{c}{4\pi}\left[U(\tau)-\mu\frac{dU(\tau)}{d\tau}\right]$$

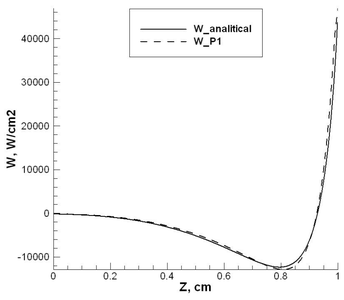


Flat computation domain

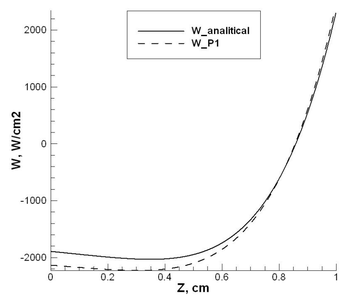


Geometry type and mesh

Heat transfer at constant absorption coefficient



Flux density, absorption 10 cm^{-1}



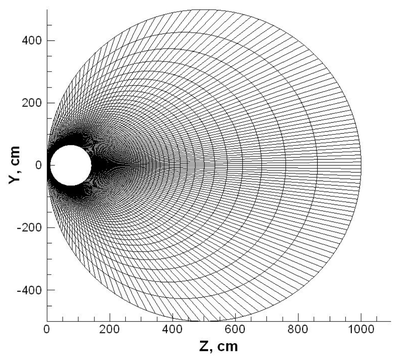
Flux density, absorption 0.1 cm^{-1}

Analytical solution for flat layer

$$W(\tau)=2\pi\left[J^+(\tau=0)E_3(\tau)+\int_0^\tau J_b\left[T(\tau')\right]E_2(\tau-\tau')d\tau'\right]-$$
$$-2\pi\left[J^-(\tau=\tau_H)E_3(\tau_H-\tau)+\int_\tau^{\tau_H} J_b\left[T(\tau')\right]E_2(\tau'-\tau)d\tau'\right],$$

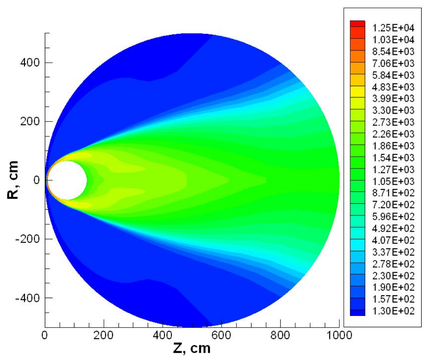
E_3, E_2 - integral-exponential functions of Chandrasekhar
τ - optical thickness
J_b - radiation intensity of black body

Spherical computation domain

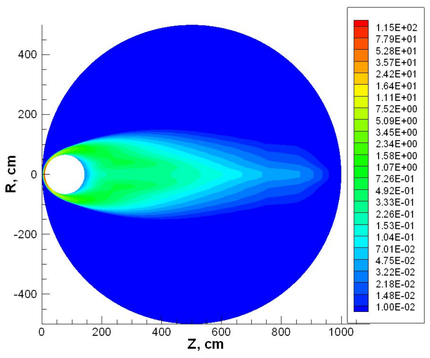


Geometry type and mesh

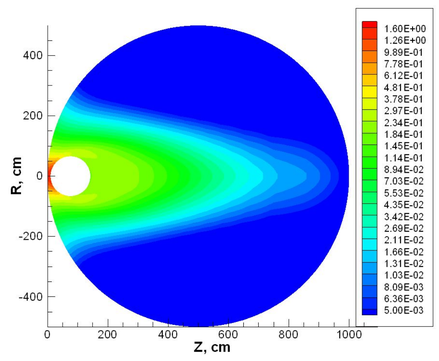
Heat transfer at constant absorption coefficient, comparing with ray-tracing method (RTM)



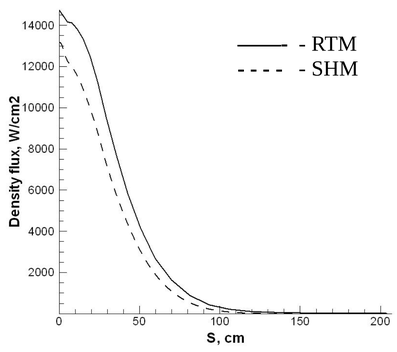
Temperature distribution, K



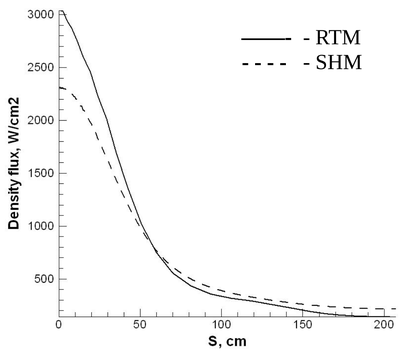
Volume density of radiation, 1 cm^{-1}



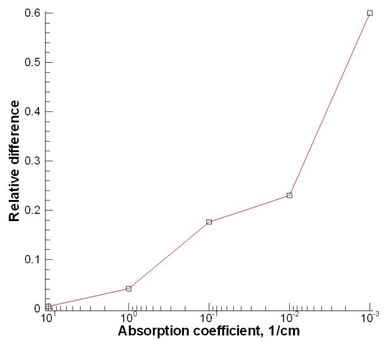
Volume density of radiation, 0.01 cm^{-1}



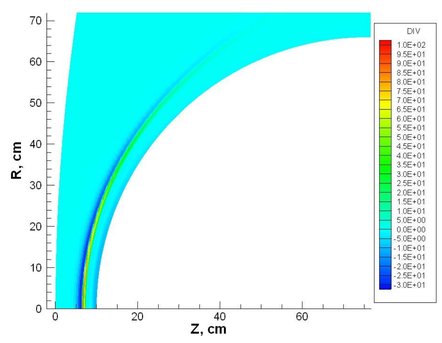
Flux density comparing, 1 cm^{-1}



Flux density comparing, 0.1 cm^{-1}

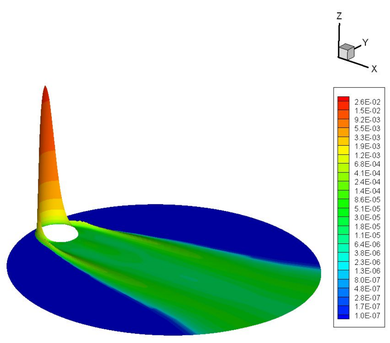


Relative difference between RTM and SHM



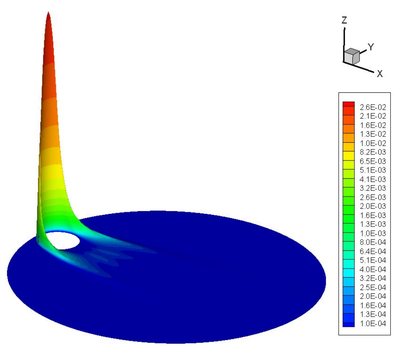
Heat generation, W/cm^3, 1 cm^{-1}

Spherical computation domain

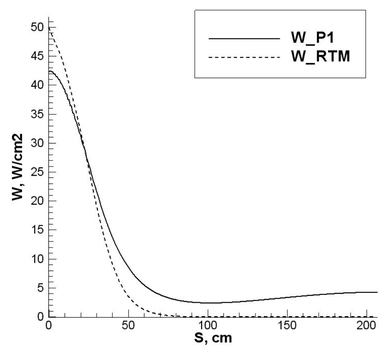


Absorption coefficient, cm^{-1}
IR spectrum range

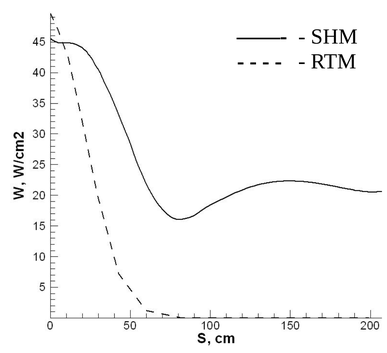
Heat transfer at real absorption coefficient, Martian atmosphere 95% CO_2 + 5% N_2



Absorption coefficient, cm^{-1}
UV spectrum range



Integral flux density, absorption limitation 0.01 cm^{-1}



Integral flux density, absorption limitation 0.001 cm^{-1}

Remarks and conclusion

- The relative difference between P_1-approximation of SHM and analytical solution for the flat geometry on uniform structured rectangular mesh not worth than 20% in wide range of absorption coefficient (10^1-10^{-3} cm^{-1})
- The relative difference between P_1-approximation of SHM and RTM for radiative transfer near spherical body increases with decreasing optical thickness
- The computational efficiency of full spectral problem can be improved by cutting of weakly absorbing spectral groups; this approximation does not influence on evaluating the maximum value of radiative heating
- The more accurate numerical exploring is required to validate tail-part of spectral radiation

Sponsors

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