ROCRAD User's Guide

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Title:	ROCRAD User's Guide
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Contents

Chapter 1

Introduction

1.1 Objectives

The objectives of the radiation module Rocrad is to take account for radiative transfer of heat released from burning aluminum droplets and aluminum oxide continuum particles, and from igniter flame in rocket simulations. In addition, it also considers radiation of emitting, absorbing and scattering particles which may vary in frequency (non-gray).

1.2 Radiation in fluid

Radiation inside solid propellant chamber can be considered as hydrodynamic radiation. For appropriate modeling, we need to understand the effect of radiation in fluid as starting point. The role of radiation in fluid is,

- as additional heat transfer mechanism to the conductive heat transfer in the equation for the rate of change of energy density,
- add radiant energy to the fluid in addition to molecular energy,
- modify fluid pressure tensor due to the present of radiation pressure tensor.

1.3 Assumptions

Simplification of in modeling can be achieved by assuming that the second and third role above are much less dominant than the first. This renders the effect of radiation only appears as a component of rate of heat transfer in the equation of conservation of energy. Further assumption is that we consider only gray gas for now, neglecting the fact that different particles may emit or absorb heat at different frequency. As first model, we assume that the fluid inside propellant chamber is optically thick. This assumption is valid only during steady burning and away from the propellant surface. It is not valid either during the ignition process of solid rocket motor.

1.4 Building and Running

To include radiation module when creating the executable, user has to compile and link subroutines in directory *rocrad*. This is done automatically by adding option ROCRAD=1 after the compilation command *gmake* in the main directory *RocfluidMP*. To compile with the structured grid code is e.g. 'gmake RFLO=1 RADI=1 MPI=1'. The executable, i.e. *rflomp* for RFLO or *rflump* for RFLU, is then created in directory *RocfluidMP*. The sample input data as outlined below in Chapter Examples and Test Problems is stored in directory RocfluidMP/Data/.

Chapter 2

Rocrad I/O Files

2.1 Input Files

2.1.1 [*CaseName*].inp file

```
# RADIATION
BLOCK  0  0        ! applies to block ... (0 0 = to all)
RADIMODEL   0      ! 0=no-radiation 1=DA-Ross. 2=DA-PN 3=RTE-gray 4=RTE-band
MEDIA       1      ! 1=artificial 2=real
                   ! all following optical const. relevant for artif. media
                   ! only VFRAC (should be 1.0) and QE relevant for real media
CONPARTVFRAC 0.0   ! continum particles mean volume fraction
CONPARTDIAM  1.E-6 ! continum particles mean particle diameter
CONPARTQE    3.0   ! continum particles mean extinction efficiency
DISPARTVFRAC 0.0   ! discrete particles mean volume fraction
DISPARTDIAM  1.E-5 ! discrete particles mean particle diameter
DISPARTQE    3.0   ! discrete particles mean extinction efficiency
SOLMETHOD   0      ! 0=no-RTE 1=DOM4 2=DOM8 3=DOM16 4=FVM (no effect if DA)
NPOLAR      1      ! number of polar intervals     (only for RTE-FVM)
NAZIMUTHAL  1      ! number of azimuthal intervals (only for RTE-FVM)
NINTANGLES  1      ! number of intensity angles (only relevant for DA)
                   ! following: intensity angles in polar and azim. dir. [deg]
POLANGLES   45.
AZIANGLES   45.
#
```

2.2 Output Files

There is no output file for instantaneous radiation quantities. Statistics of radiation quantities are currently not required. The surface radiation flux is directly delivered to Genx to be used by other groups, such as combustion group to better mimic the radiative heet feedback to the propellant surface.

Chapter 3

Examples and Test Problems

3.1 Radiative equilibrium test case

The objective of this test case is to represent coupled hydrodynamic radiation phenomena within rocket chamber and provide radiative heat feedback to the propellant surface. This heat feedback affects propellant related processes such as regression rate, radiant ignition and aluminum agglomeration. The modeling approach assumes that effect of radiation in fluid only appears as additional heat transfer, in the form of radiative flux, to the existing heat conduction in the conservative equation of energy. The role of radiant energy and radiation pressure tensor is negligible compared to the radiative flux. The diffusion approximation model is based on a further assumption that the participating media is optically thick, which is considered sensible for the flow inside rocket chamber, especially in steady burning condition. Non gray media is considered. A validation is conducted for radiative heat trasfer, compared to a reference result based on a more general formulation. The result of Rocflo converges to the reference result for increasing optical thickness, as expected.

3.1.1 radeq.inp file

```
! Input file for radiative equilibrium case

! mapping of blocks to processors ---------------------------------------------

# BLOCKMAP
NBLOCKS   0      ! no. of blocks per processor (0=automatic mapping)
#

! grid/solution format -------------------------------------------------------

# FORMATS
GRID      0      ! 0=Plot3D ASCII, 1=Plot3D binary, 2=HDF
SOLUTION  0      ! 0=ASCII, 1=binary, 2=HDF
#

! viscous/inviscid flow ------------------------------------------------------

# FLOWMODEL
BLOCK  0  0      ! applies to block ... (0 0 = to all)
```

```
MODEL     1      ! 0=inviscid (Euler), 1=viscous (Navier-Stokes)
MOVEGRID  0      ! moving grid (0=no, 1=yes)
#

! reference values -------------------------------------------------------------

# REFERENCE
ABSVEL   30.0   ! absolute velocity [m/s]
PRESS    100000. ! static pressure [Pa]
DENS     1.1250  ! density [kg/m^3]; this p and rho gives Tref =260 = Tw
CP       1004.5  ! specific heat coeff. at constant pressure [J/kgK]
GAMMA    1.4     ! ratio of specific heats
LENGTH   0.01    ! length [m]
RENUM    500.0   ! Reynolds number (lam. viscosity = dens*absvel*length/renum)
PRLAM    0.72    ! laminar Prandtl number
PRTURB   0.9     ! turbulent Prandtl number
SCNLAM   0.22    ! laminar Schmidt number
SCNTURB  0.9     ! turbulent Schmidt number
#

! viscosity model -------------------------------------------------------------

# VISCMODEL
BLOCK  0  0       ! applies to block ... (0 0 = to all)
MODEL     0       ! 0=SutherLand, 1=Fixed, 2=Antibes
VISCOSITY 6.75E-04 ! reference viscosity
REFTEMP   110.0   ! reference temperature
SUTHCOEF  288.16  ! sutherland coefficient
#

! probe ------------------------------------------------------------------------

# PROBE
NUMBER   1
1    15   15  1   ! block, icell, jcell, kcell (1=first physical cell)
#
WRITIME    1.E-3    ! time offset [s] to store probe data
WRIITER    10       ! offset between iterations to store probe data
OPENCLOSE  0        ! open & close probe file every time (0=no, 1=yes)
#

! forces -----------------------------------------------------------------------

# FORCES
TYPE     1       ! 0=no forces calculated, 1=pressure forces, 2=1+viscous forces
#

! multi-physics modules: -------------------------------------------------------

# PERIODICFLOW
BLOCK  0  0      ! applies to block ... (0 0 = to all)
FLOWKIND  0      ! 0=none, 1=CPR, 2=channel
#

# TURBULENCE
BLOCK  0  0      ! applies to block ... (0 0 = to all)
TURBMODEL  0     ! 0=laminar, 1=...
#

# SPECIES
BLOCK  0  0      ! applies to block ... (0 0 = to all)
MODEL  0         ! 0=perfect gas, 1=...
#
```

```
# CONPART
BLOCK  0  0      ! applies to block ... (0 0 = to all)
USED   0         ! 0=module not used
#

# DISPART
BLOCK  0  0      ! applies to block ... (0 0 = to all)
USED   0         ! 0=module not used
#

# RADIATION
BLOCK  0  0      ! applies to block ... (0 0 = to all)
RADIMODEL   1      ! 0=no-radiation 1=DA-Ross. 2=DA-PN 3=RTE-gray 4=RTE-band
MEDIA       1      ! 1=artificial 2=real
                   ! all following optical const. relevant for artif. media
                   ! only VFRAC (should be 1.0) and QE relevant for real media
CONPARTVFRAC 0.10  ! continum particles mean volume fraction
CONPARTDIAM  9.E-4 ! continum particles mean particle diameter
CONPARTQE    3.0   ! continum particles mean extinction efficiency
DISPARTVFRAC 0.0  ! discrete particles mean volume fraction
DISPARTDIAM  1.E-3 ! discrete particles mean particle diameter
DISPARTQE    3.0   ! discrete particles mean extinction efficiency
SOLMETHOD   0      ! 0=no-RTE 1=DOM4 2=DOM8 3=DOM16 4=FVM (no effect if DA)
NPOLAR      1      ! number of polar intervals     (only for RTE-FVM)
NAZIMUTHAL  1      ! number of azimuthal intervals (only for RTE-FVM)
NINTANGLES  1      ! number of intensity angles (only relevant for DA)
                   ! following: intensity angles in polar and azim. dir. [deg]
POLANGLES   45.
AZIANGLES   45.
#

! time-stepping control --------------------------------------------------------

# TIMESTEP
FLOWTYPE   0      ! 0=steady flow, 1=unsteady flow
TIMESTEP   1.E-5  ! max. physical time step [s]
STARTTIME  0.0  ! current time 1.E-03
MAXTIME    1.E-1 ! max. time simulated [s]
WRITIME    1.E-6  ! time offset [s] to store solution
PRNTIME    1.E-6  ! time offset [s] to print convergence

! if FLOWTYPE=0
STARTITER  0   ! current iteration
MAXITER    1     ! max. number of iterations
RESTOL     1.E-5  ! max. density residual to stop iterations
WRIITER    4000    ! offset between iterations to store solution
PRNITER    1      ! offset between iterations to print convergence
#

! time averaged statistics for unsteady flow -----------------------------------

# STATISTICS
DOSTAT     0     ! 1=ON, 0=OFF
RESTART    0     ! restart switch: 1 = continued process, 0 = new process
MIXTNSTAT  11    ! number of mixture statistics with their ID's below
MIXTSTATID 01 02 03 04 05 22 33 44 23 34 24
                 ! 1=rho 2=u 3=v 4=w 5=T 6=p 7=vsound 8=muel 9=tcol 22=uu etc
TURBNSTAT  3     ! number of mixture statistics with their ID's below
TURBSTATID 01 02 03
                 ! 1=muet 2=tcot 3=cdyn
#

! numerics ---------------------------------------------------------------------
```

```
# MULTIGRID
START    1       ! at which grid level to start (>0; 1=finest grid)
CYCLE    0       ! 0=no MG, 1=V-cycle, 2=W-cycle
REFINE   99999   ! no. of iterations before switching to next finer grid
#

# NUMERICS
BLOCK    0  0    ! applies to block ... (0 0 = to all)
CFL      7.0     ! CFL number
SMOOCF   0.70     ! coefficient of implicit residual smoothing (<0 - no smooth.)
DISCR    0       ! type of space discretization (0=central, 1=Roe, 2=MAPS)
K2       0.0     ! dissipation coefficient k2 (if discr=0)
1/K4     128.    ! dissipation coefficient 1/k4 (if discr=0)
PSWTYPE   0      ! 0=standard pressure switch, 1=TVD type (if discr=0)
PSWOMEGA  0.1    ! blending coefficient for PSWTYPE=1 (if discr=0)
ORDER    2       ! 1=first-order, 2=second-order, 4=fourth-order
LIMFAC   5.0     ! limiter coefficient (if discr=1)
ENTROPY  0.05    ! entropy correction coefficient (if discr=1)
#
```

3.1.2 radeq.top file for single processor run

```
# topology file for radiative equilibrium case
#
 1      ! total no. of blocks
 1  1   ! block, no. of grid levels
 6  64   64  2           ! no. of patches, icells, jcells, kcells
110  1  -1 -64   1   2    1   2  -1 -64   1   2   0
110  2  -1 -64   1   2    1   1  -1 -64   1   2   0
 70  3   1   2   1  64    0   0   0   0   0   0   0
 70  4   1   2   1  64    0   0   0   0   0   0   0
100  5   1  64   1  64    0   0   0   0   0   0   0
100  6   1  64   1  64    0   0   0   0   0   0   0
```

3.1.3 Result of radiative equilibrium case

The computational configuration of radiative equilibrium case is shown in 3.1, representing parallel plates having different temperature with static participating media in between. The optical thickness of the media is adjustable. Result of the radiative equilibrium case is shown in Figure 3.2 - 3.3. In Figure 3.2, the radiation temperature profile betweem the two plates is presented. Radiation flux resulting from Rocflo (diffusion approximation model) is compared to numerical result of Loyalka, based on general (RTE) formulation (j. heat mass transfer 12, 1969) as shown in Figure 3.3. It is clearly seen that the radiation flux converges to the general solution with increasing optical thickness, as expected.

Bibliography

[1] Loyalka, S.K.,(1969). Shorter communications: Radiative heat transfer between parallel plates and concentric cylinders. *J. Heat Mass Transfer*, **12**, 1513-1517.

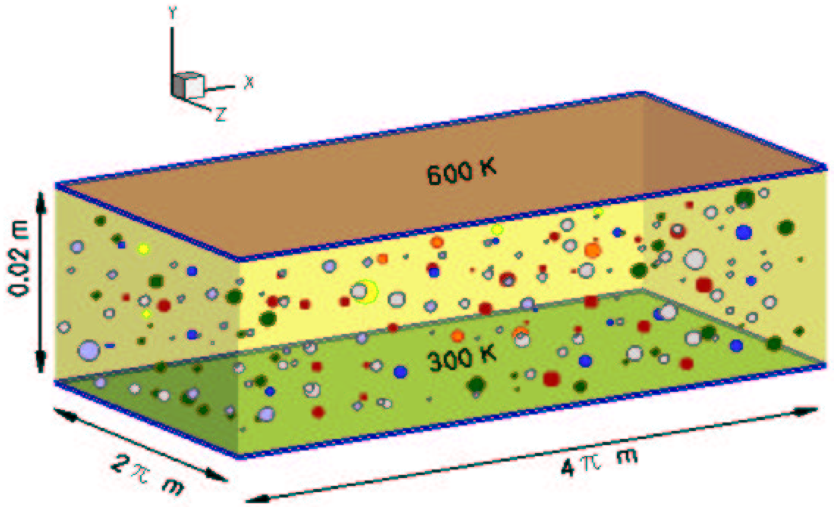

Figure 3.1: Computational configuration of radiative equilibrium case represented by parallel plates having different temperature with static participating media in between.

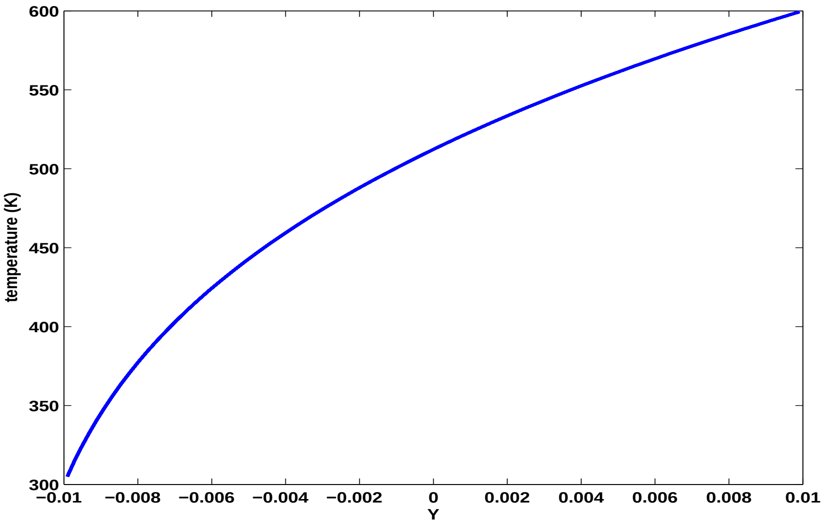

Figure 3.2: Radiation temperature profile resulting from Rocflo using diffusion approximation model.

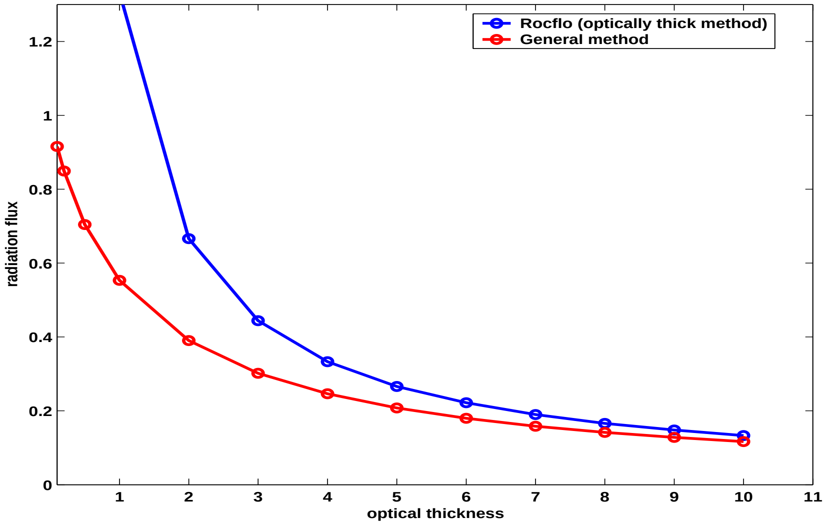

Figure 3.3: Radiation flux resulting from Rocflo (diffusion approximation model) compared to numerical result of Loyalka, based on general (RTE) formulation (j. heat mass transfer 12, 1969).