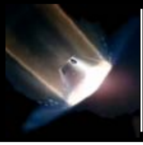

Optimizing a Coupled Solution for the Orion MPCV Using DPLR and NEQAIR

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TSA

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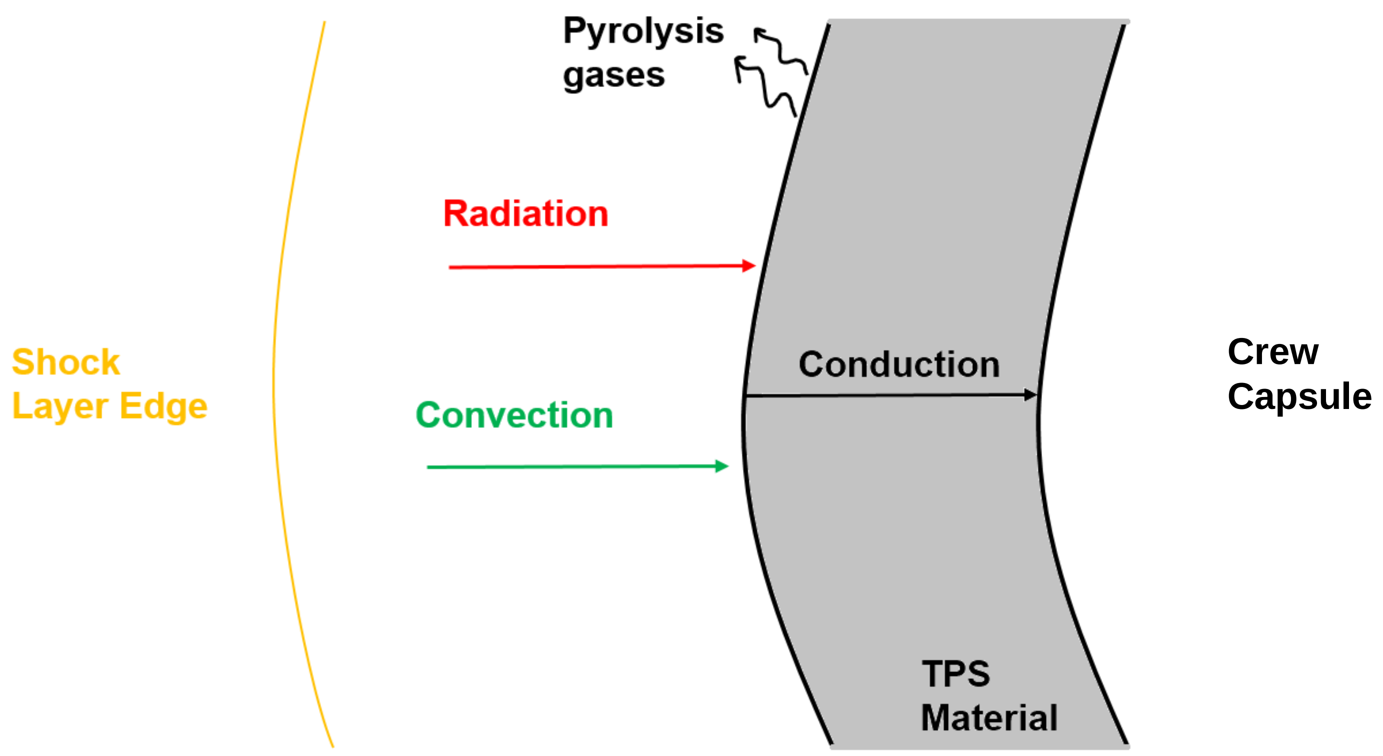
Overview

- Background
- Significance
- Approach
- Data
- Results & Future Work

Background

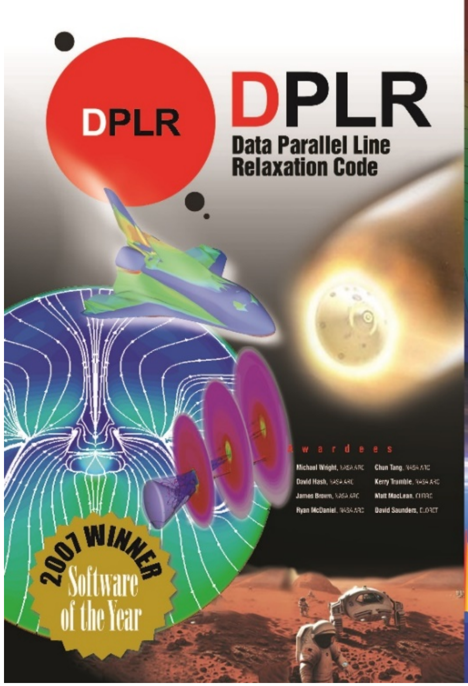
- Aerothermal CFD has shown that there are two important types of heating on Hypersonic Entry
  - **Radiative** and **Convective** Heating



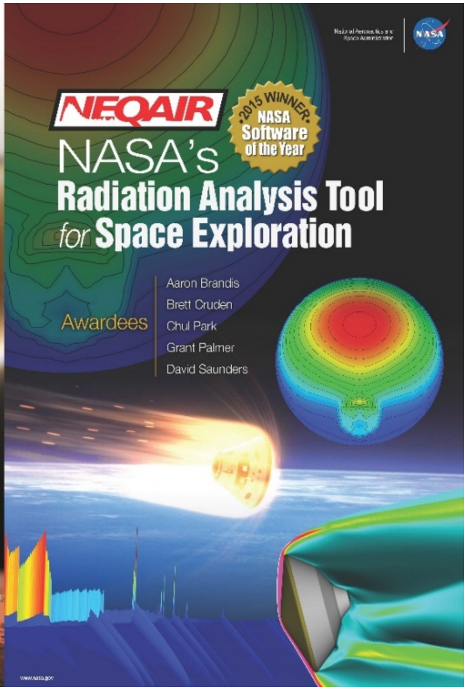
Background (cont.)

- Normal CFD solvers can only solve for convective or radiative heating one at a time
  - Few are able to “couple” the two accurately
  - But a production ready tool is under way…

DPLR – Data Parallel Line Relaxation Code



NEQAIR – Nonequilibrium Air Radiation Code



Background (cont.)

DPLR

Initial DPLR grid and solution files **copied** from external location to a local working directory.

DPLR - LOS

The ‘dplr_los’ program **partitions DPLR data into HDF5 files** for NEQAIR. Each HDF5 file has a series of wall-normal lines for NEQAIR to calculate.

NEQAIR

The ‘postflow’ program is run on the stored files to **extract species number densities**, T_{tr}, and T_v from the cell centers, which is output on the grid vertices.

For each HDF5 file, a NEQAIR job is executed. NEQAIR outputs the **net energy lost/gained along a given line** and appends it to the original HDF5 file.

The ‘dplr_los’ program is run again to **reassemble radiation source data** into a single file for use with DPLR, ‘qrad.prda’.

DPLR is run again to **re-converge the flow field** with the NEQAIR-derived radiation source term.

Repeat for each iteration

Coupler Iteration	**1**	**2**	**3**	**4**	**5**
Radiation Source Term Scaling	0.6	0.8	0.9	1	1

Background (cont.)

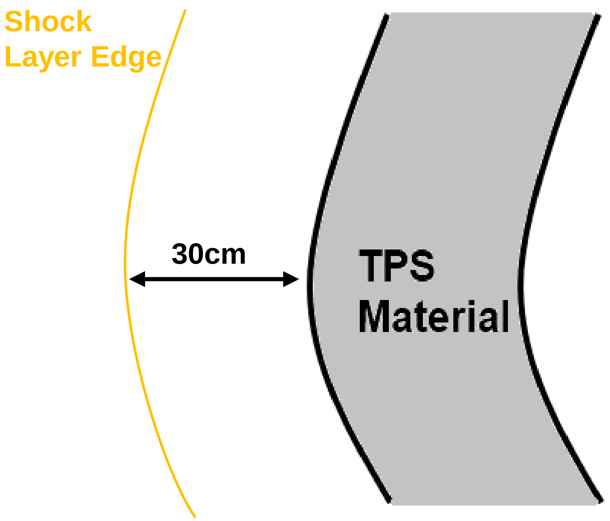
- The Coupling Setup script enables the user to easily control parameters

- Each iteration can be tailored with the number of CFD iterations and coarsening of the “radiation grid”

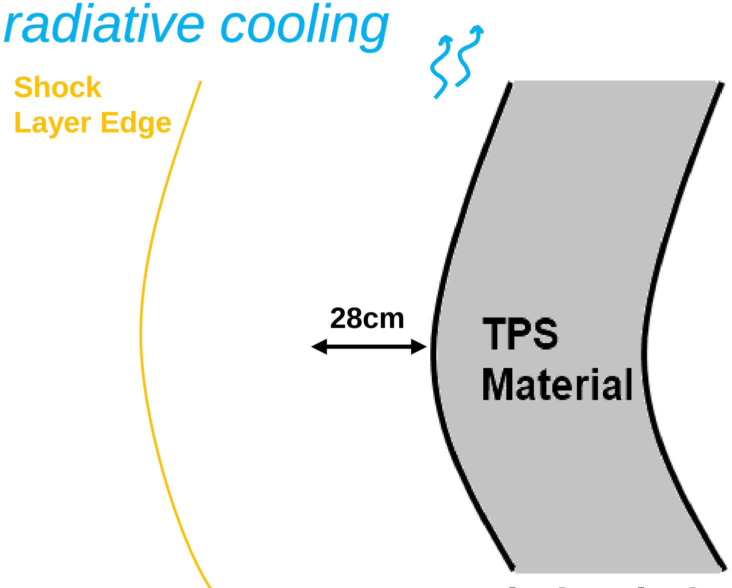
```
[COUPLER_SETUP]
iterations   = 5
prefix       = run

[DPLR_SETUP]
input_dir   = inputs
inputfile   = dplr.inp
gridfile    = cev.111.pgrx
flowfile    = cev.111.pslx
prefix      = dplr
dimension   = 2
normal_line = j

[NEQAIR_SETUP]
input_dir   = inputs
inputfile   = neqair.inp
prefix      = neqair
batch_jobs  = 16

[OPTIONS]
# All items are list with 1 entry per coupling iteration
dplr_igalign       = 0,    0,    1,    1,    1
dplr_istop         = 5000, 5000, 3500, 3500, 3500
coupler_iskip      = 2,    1,    1,    1,    1
coupler_jskip      = 2,    1,    1,    1,    1
coupler_scale_divq = 0.6,  0.8,  1.0,  1.0,  1.0

[DPLR_BATCH]
nprocs    = 100
walltime  = 03:00:00
jobname   = couple_dplr
queue     = batch
stdout    = run_dplr.out

[NEQAIR_BATCH]
nprocs    = 64
walltime  = 04:00:00
jobname   = couple_neqair
queue     = batch
stdout    = run_neqair.out

[D2N_BATCH]
walltime  = 00:30:00
jobname   = couple_d2n
stdout    = run_d2n.out

[N2D_BATCH]
walltime  = 00:30:00
jobname   = couple_n2d
stdout    = run_n2d.out

[SYSTEM_SETUP]
setup_commands = ulimit -s unlimited
```

Significance

- Most flow simulations can get away with being uncoupled or loosely coupled because the radiative energy is minimal compared to the total energy of the gas
  - However, for high-speed entries, radiative energy is a major sink in the shock layer and a source in the boundary layer, which reduces the bow shock standoff distance and reduces the convective and radiative heating rates at the wall
  - This phenomenon is known as *radiative cooling*



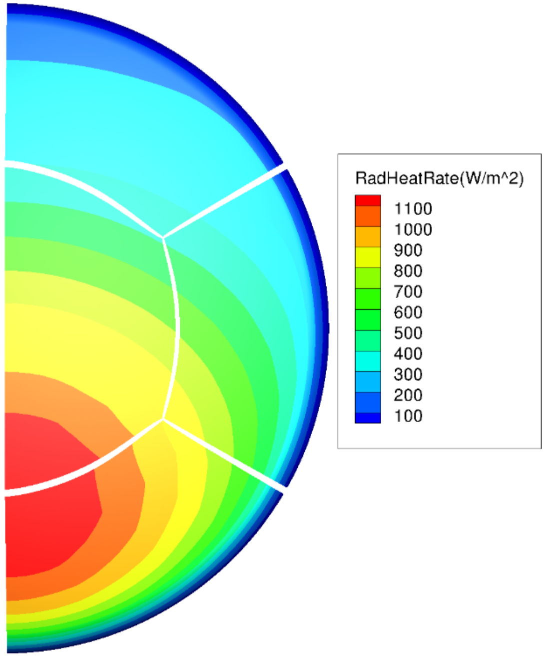
Uncoupled Solution



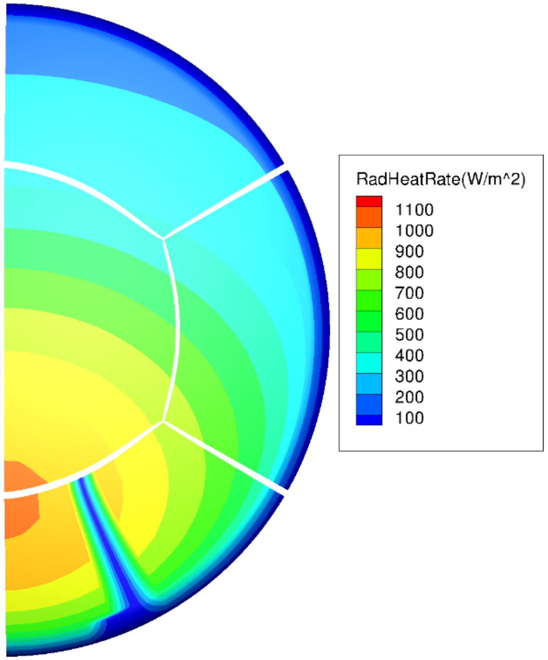
Coupled Solution

Significance

- Another way to show the effect of *radiative cooling* is on the forebody surface. For uncoupled solutions, the implied margin is higher and so a more conservative estimate is required.



Uncoupled Solution



Coupled Solution

Significance

More accurate modeling

of the heating effects

↓

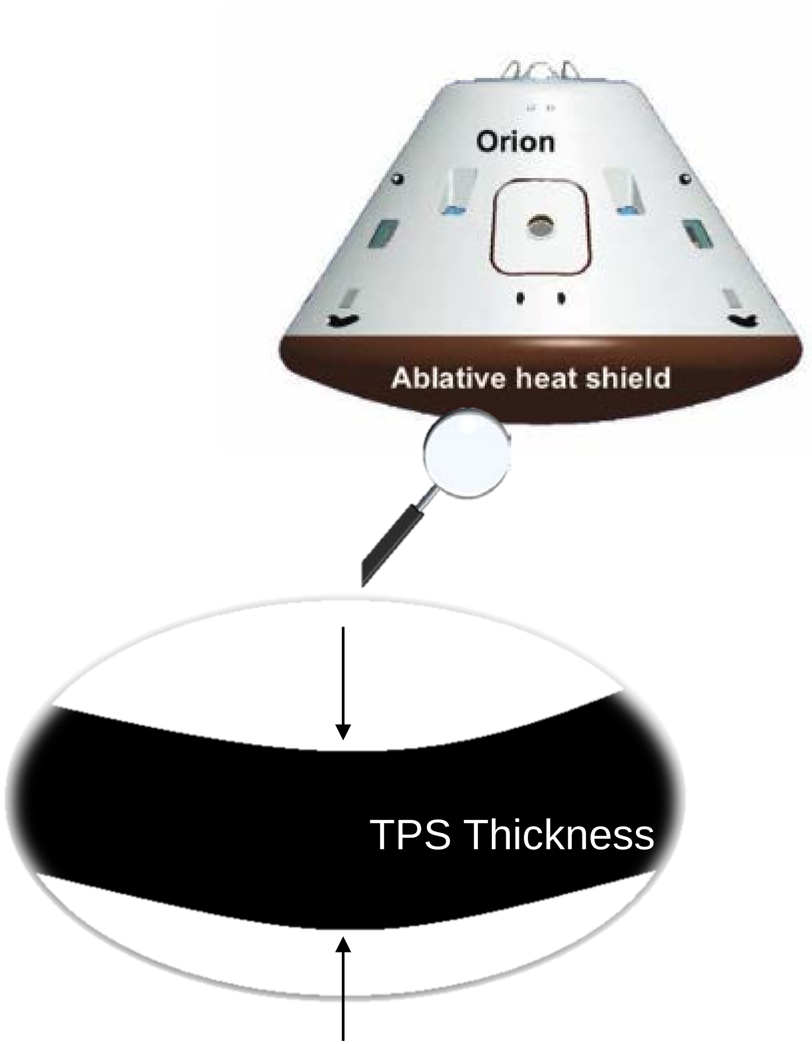
Slimmer Design Margins

↓

Thinner TPS/Reduced weight

↓

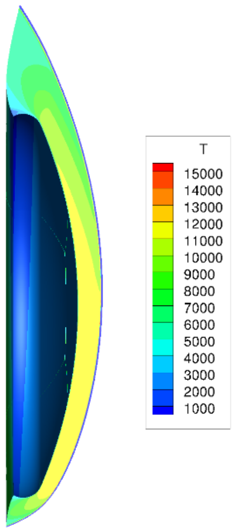
More weight for mission critical elements (science instruments, food, sensors, etc.)



My Objectives

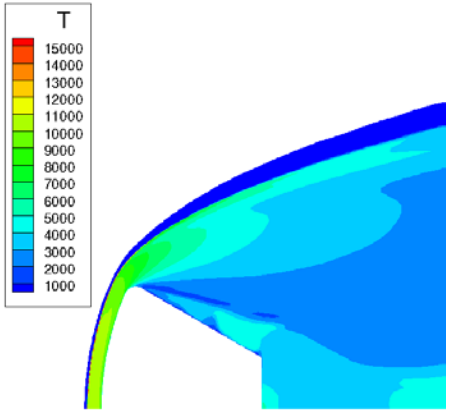
Objective 1:

Successfully run a 3D Orion MPCV simulation through the coupler



Objective 2:

Optimize run time of Orion MPCV by testing run time of 2D case through the coupler



My Approach

Started with a low velocity (5km/s) 2D axi-symmetric case to validate coupler would work

Coupler Bug Found: wouldn't write out all 'qrad' lines for multi-block problems

After coupler fixed, ran 3D half body case at 5km/s to ensure 3D could work in coupler

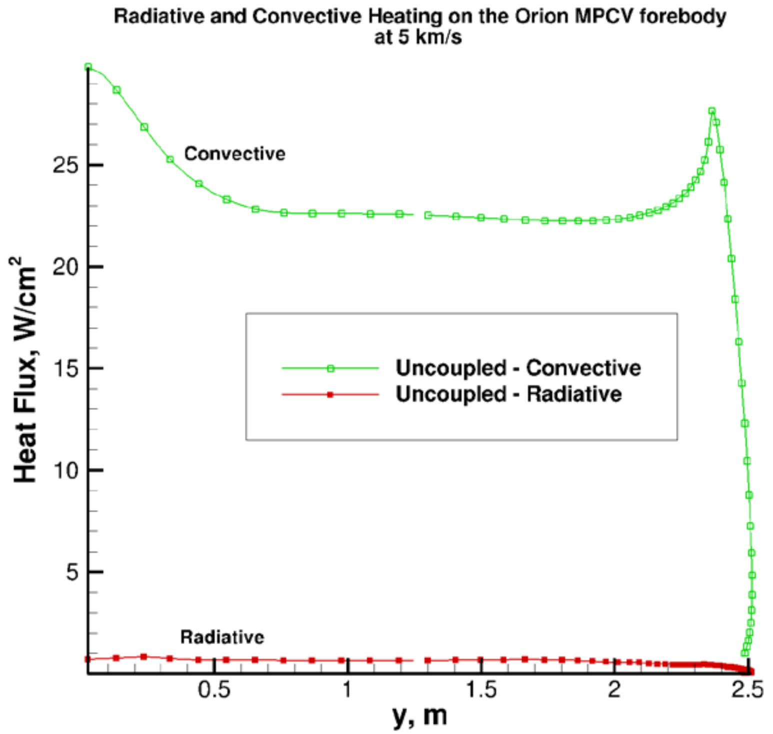
Went back to 2D and began running at peak heating condition (10km/s)

NEQAIR Update: "Ill-conditioned" math lines were hung, fix put in to skip hanging

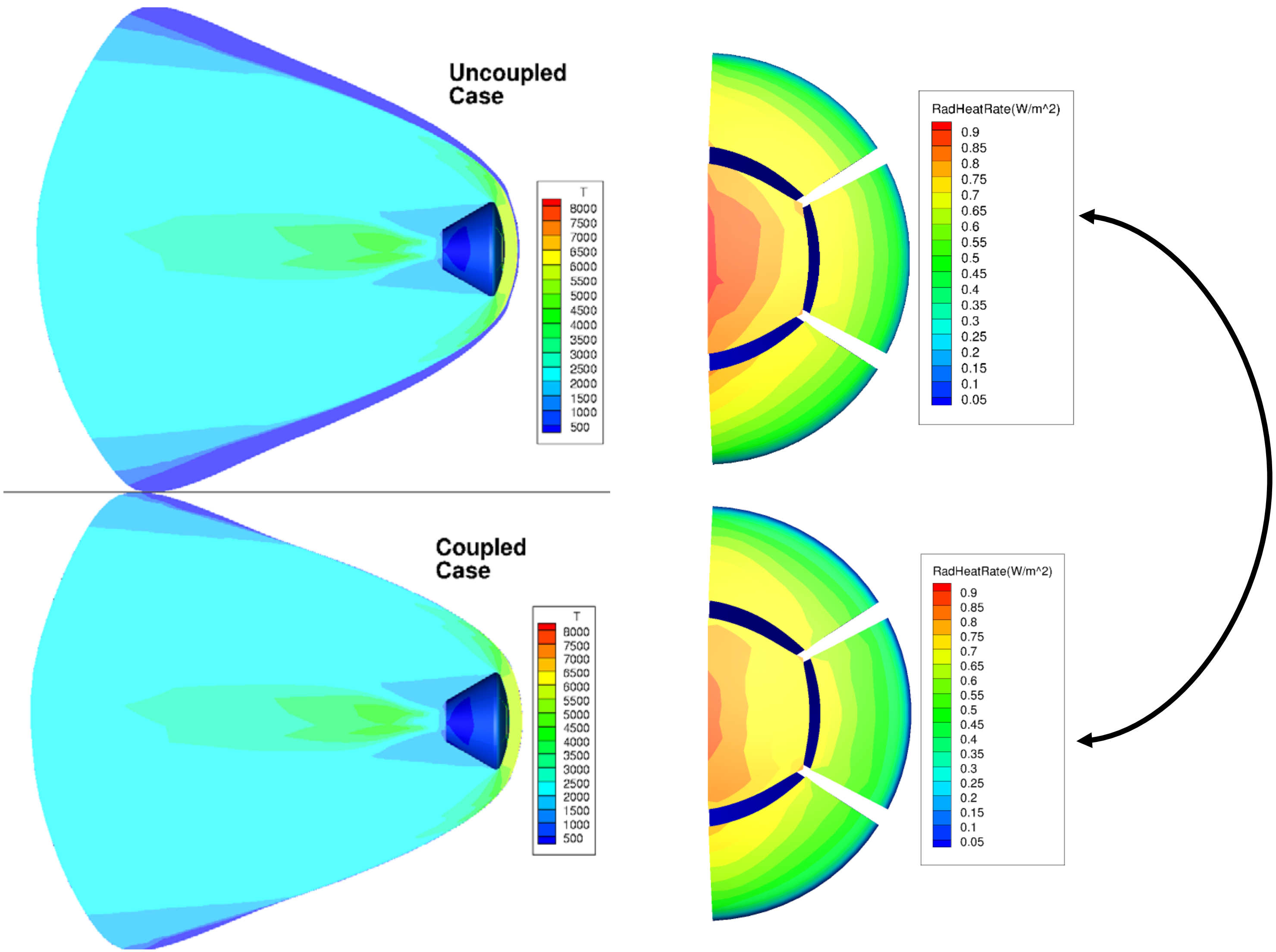
Began running 3D case at peak heating conditions (10km/s) and examined forebody conditions

2D Axi-Symmetric Case (5km/s, 54.6km)

- In order to sort out bugs in the coupler, a 2D case was ran through
  - Several bugs were found in the coupler source code that prevented NEQAIR from working
  - Note how the **Radiative Heating is much lower than the Convective Heating** at 5 km/s



3D Half Body (5km/s, 54.6km, 0’AoA)

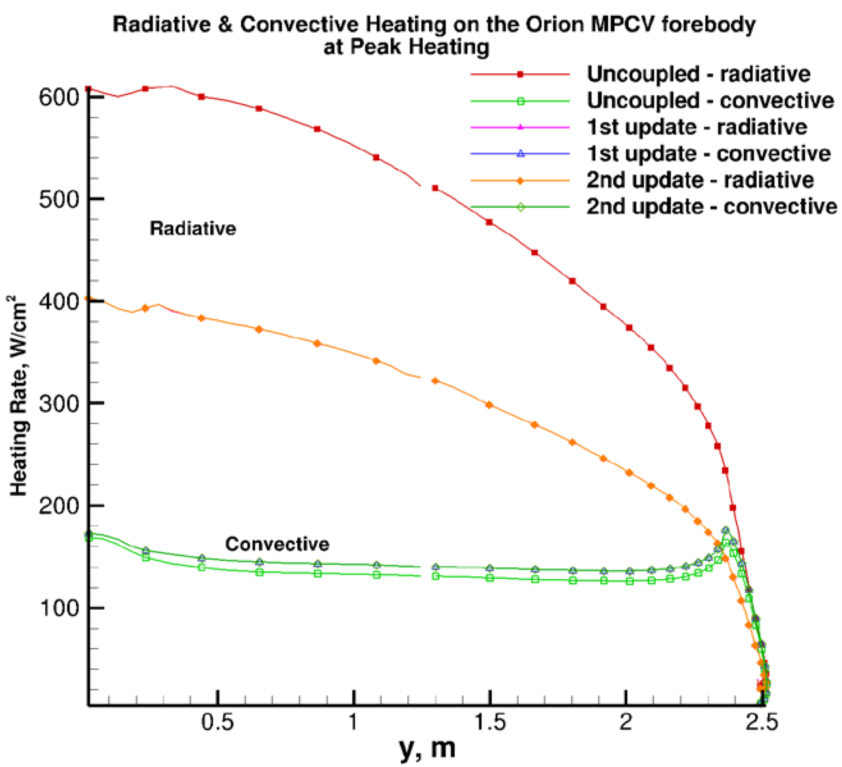


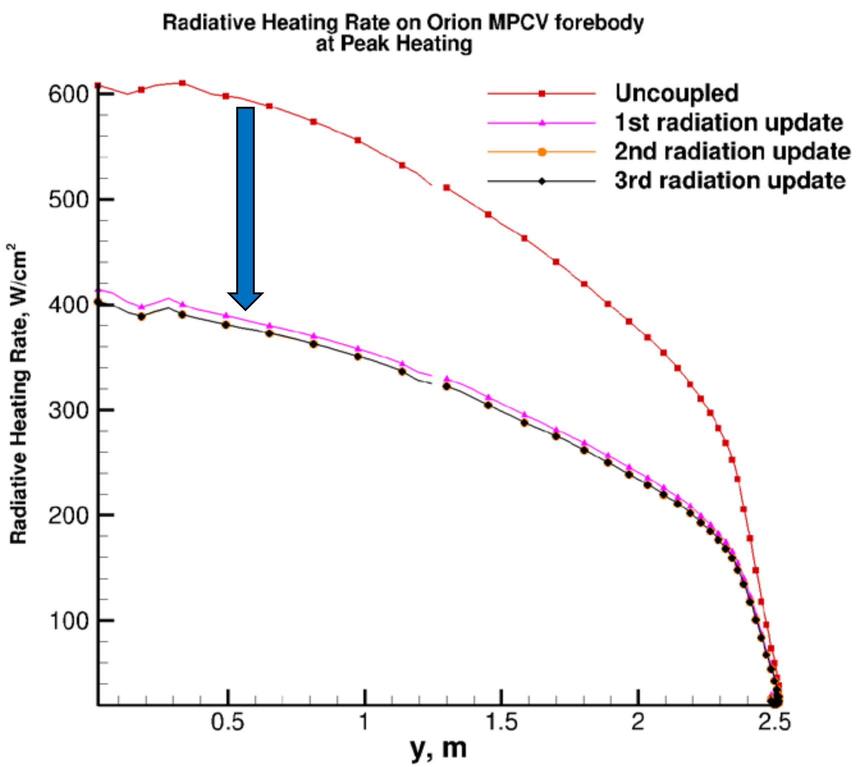
Note - the Coupled Case has **lower** radiative heating than the Uncoupled

2D Peak Heating (10.5km/s, 61km)

At high entry speeds, the radiative heating becomes **much greater** than the convective heating

As progressive runs are done, the radiative heating on the forebody converges to a **lower value**





2D Peak Heating (10.5km/s, 61km)

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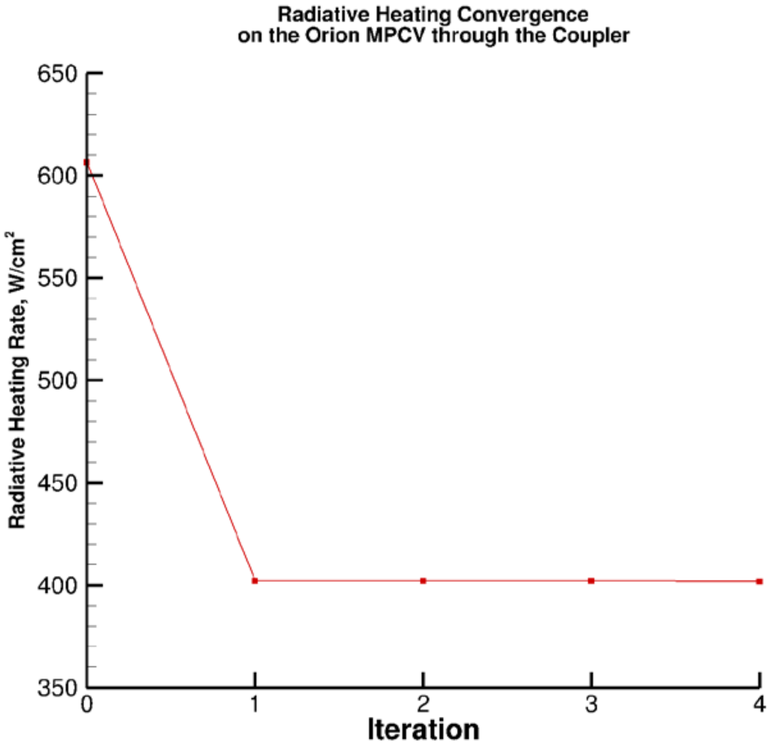
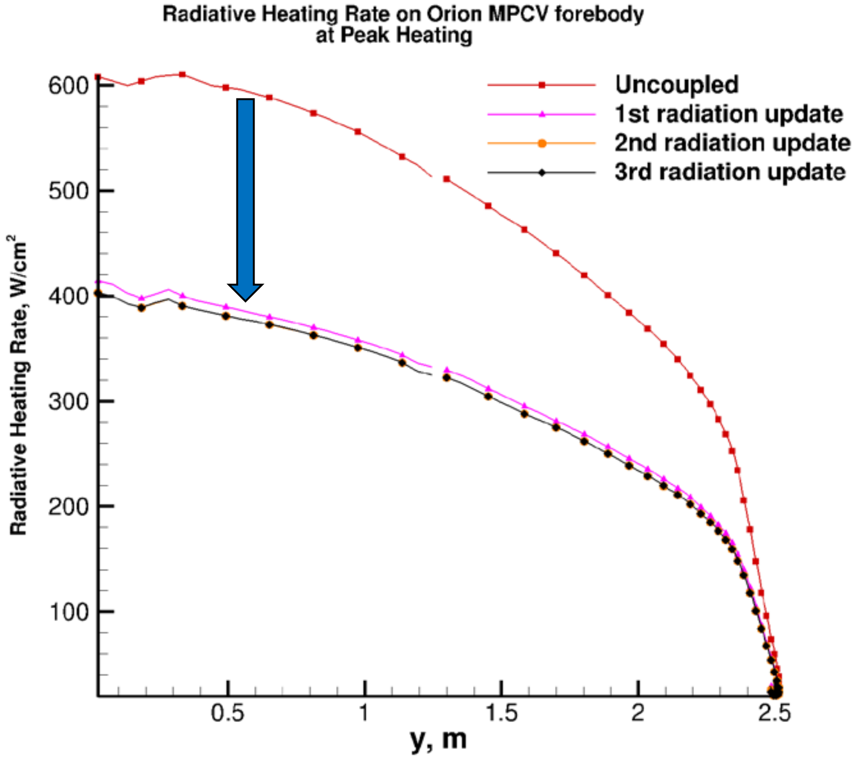
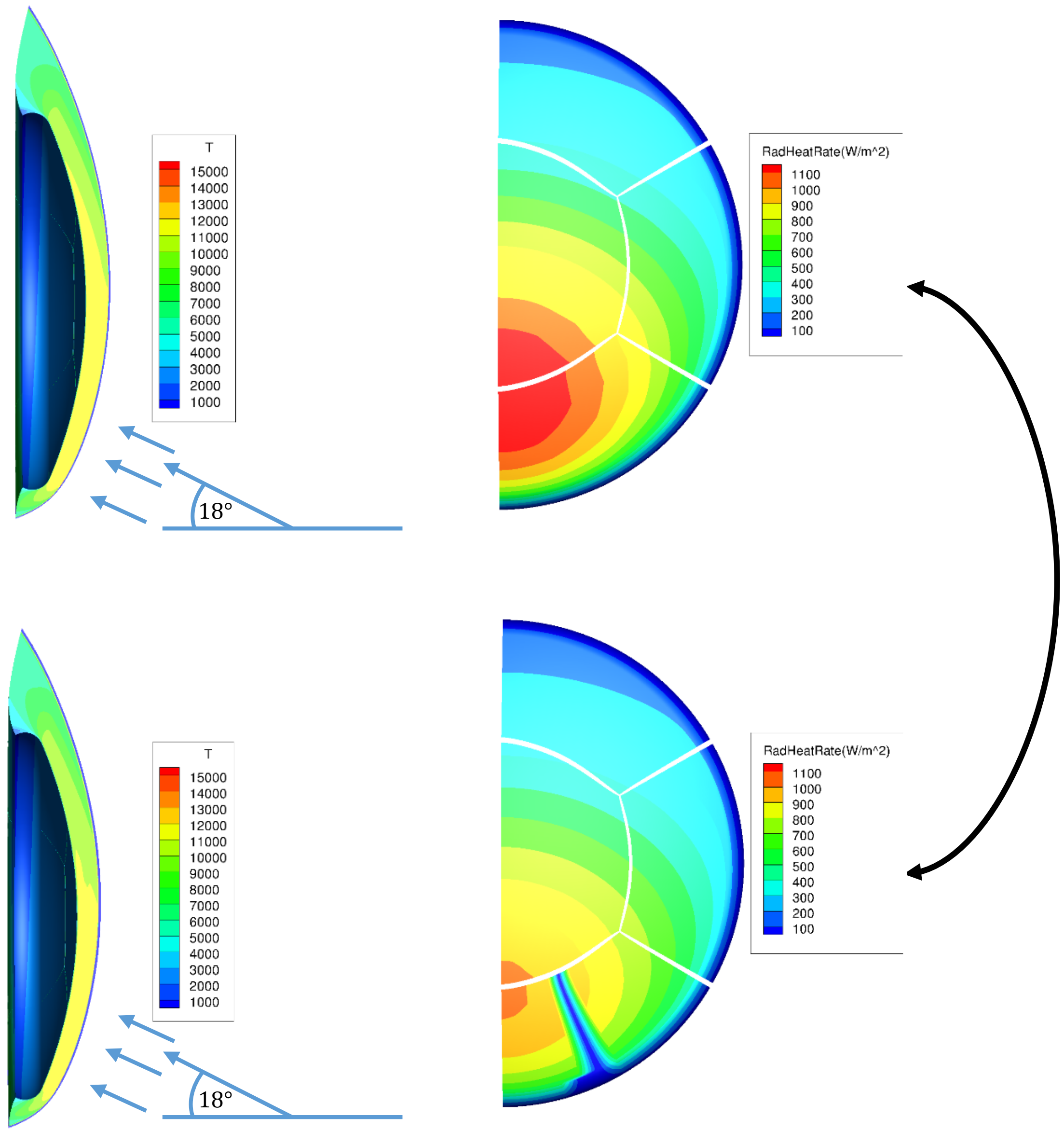




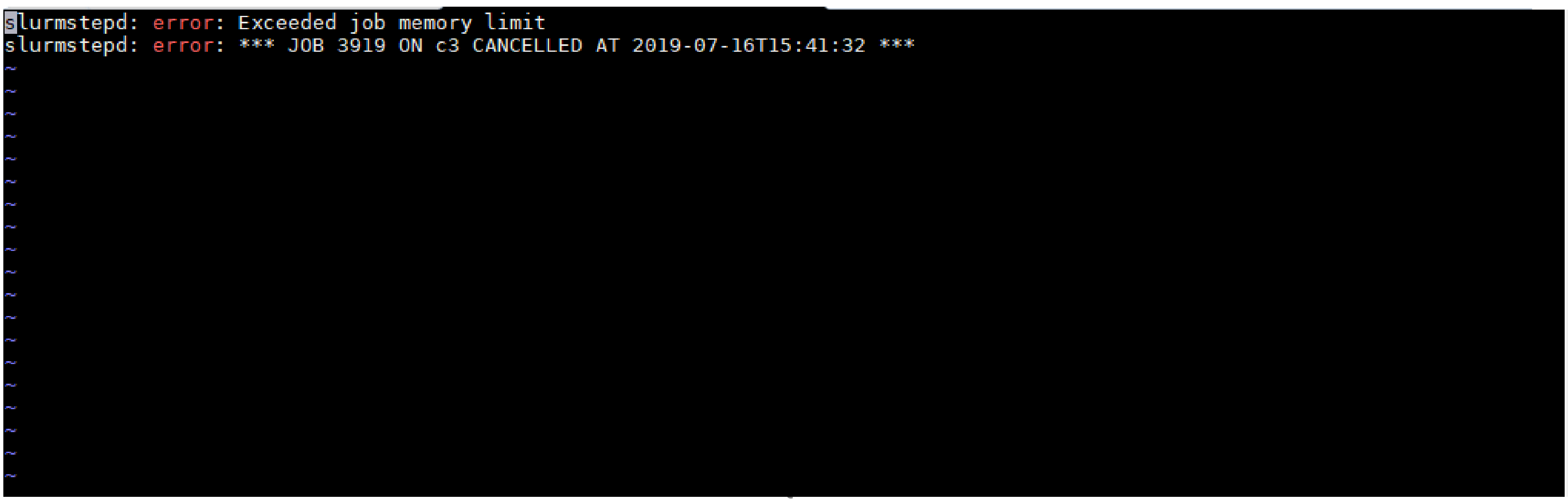
3D Peak Heating (10.5km/s, 61km,18’AoA)



Note - the Coupled Case has **much lower** radiative heating than Uncoupled

Discussion/Conclusions

- The 3D **<u>case is set up and can run several steps</u>** through the coupler
  - Recommend that # of batch jobs be split up to 32 and the number of NEQAIR lines be coarsened from 8, to 4, to 2
  - Computational Time: running with 256 processors per NEQAIR file and 300 processors for DPLR
    - Switch from Cedar to Pleiades will speed this up dramatically
- Still errors with some of the NEQAIR lines



Future Work

- Tweak the 3D coupled case further in order to fix NEQAIR stability issues
  - Move from Cedar to Pleiades
- Set up the 3D case to run through a database of entry conditions
  - Varying entry speeds, angle of attack, and altitudes
  - Already done for 2D, still needs to be done for 3D

Lessons Learned

Start Small

- Work from a simple 2D case and troubleshoot errors before running a larger case

Adapt First

- Adapt the uncoupled solution before running it through the coupler

Boundary Conditions

- Check that your boundary conditions are correct *before* starting or else your solution will not converge

Works Cited & Acknowledgements

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Palmer, Grant E., et al. “Direct Coupling of the NEQAIR Radiation and DPLR CFD Codes.” *Journal of Spacecraft and Rockets*, vol. 48, no. 5, 2011, pp. 836–845., doi:10.2514/1.52043.

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Questions?

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