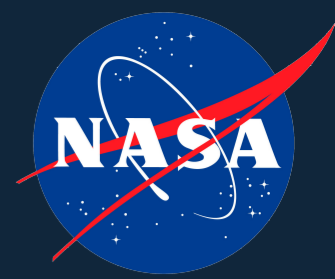


An approach to solving enclosure radiation problems in a multi-physics context



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Background

Thermal protection system (TPS) analysis of complex features or damage sites can sometimes require modeling of high temperature enclosures.

Implementing efficient and accurate view-factor algorithms required to model such problems is complex [2]. In this work, the Non-Equilibrium Radiation Solver (NERO) [1] is used to model radiating enclosures by augmenting the boundary conditions. The Ares [3] multi-physics platform is used to couple the material response, through Icarus [4], with the radiation solver to time-accurately model the wall temperature.

Methodology

NERO is a radiation modeling software that solves the radiative transport equation in a finite-volume scheme. In this work, the boundary conditions for the radiation solver are augmented to account for emission, absorption, and reflection. This means that for a given radiative flux that reaches a wall, part of the flux is absorbed, part is re-emitted, and part is reflected. Thus, when the system is converged, the enclosed nature of the modeled geometry is naturally captured.

Benefits of the approach

- Bypass calculation of view-factors
- Allows for participating media
- Can be used to derive effective emissivity factors for TPS design applications
- Is relatively inexpensive
- Geometric complexity agnostic
- Symmetric boundary conditions naturally captured

Verification

Two verification exercises are conducted against analytical solutions.

Parallel Plates

The first problem consists of two parallel semi-infinite plates at different temperatures, as illustrated in Fig. 1. This exercise is repeated for different values of emissivity. The results, in Fig. 1b, show that the methodology agrees with the analytical solution with less than 2% error. Figure 1b also shows how the error changes based on the discretization of the angular integration (number of directions).

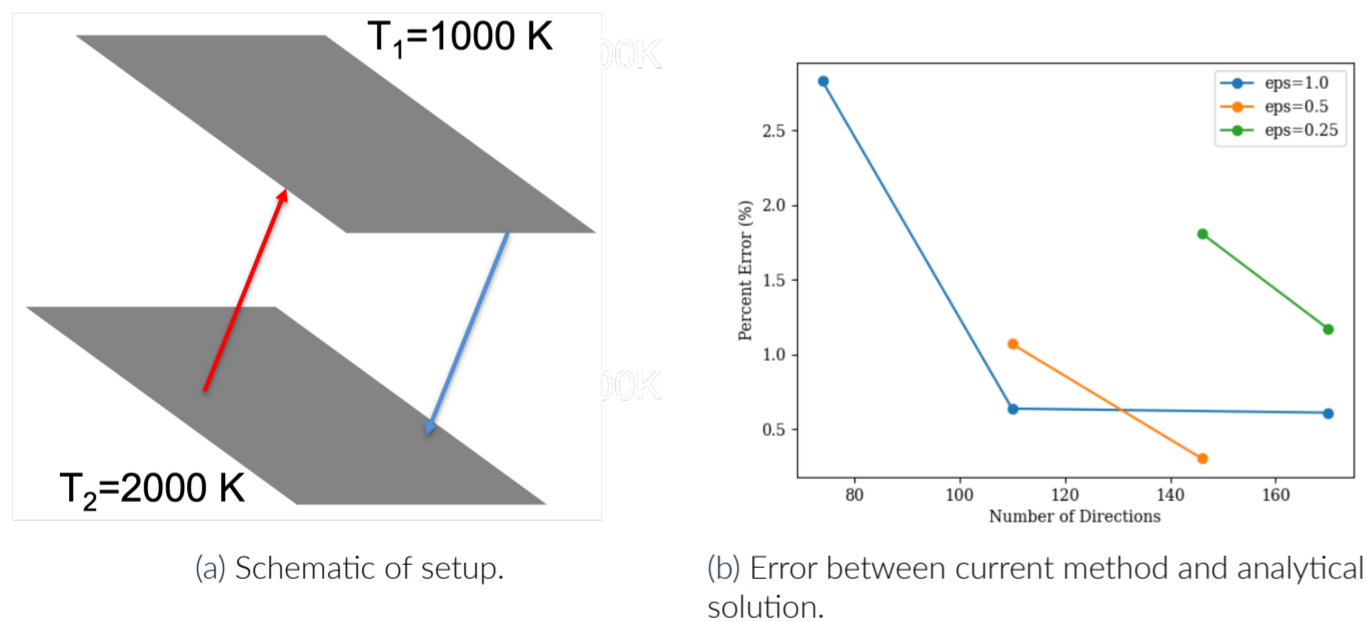


Figure 1. Parallel plates analytical solutions

Hollow cylinder

The second problem is a self-radiative hollow semi-infinite cylinder. The cylinder presents with an angular distribution of wall temperature following the expression $T = T_0 \cos(\theta/2)^{1/4}$. Figure 2 shows the analytical solution and the error as a function of angle θ .

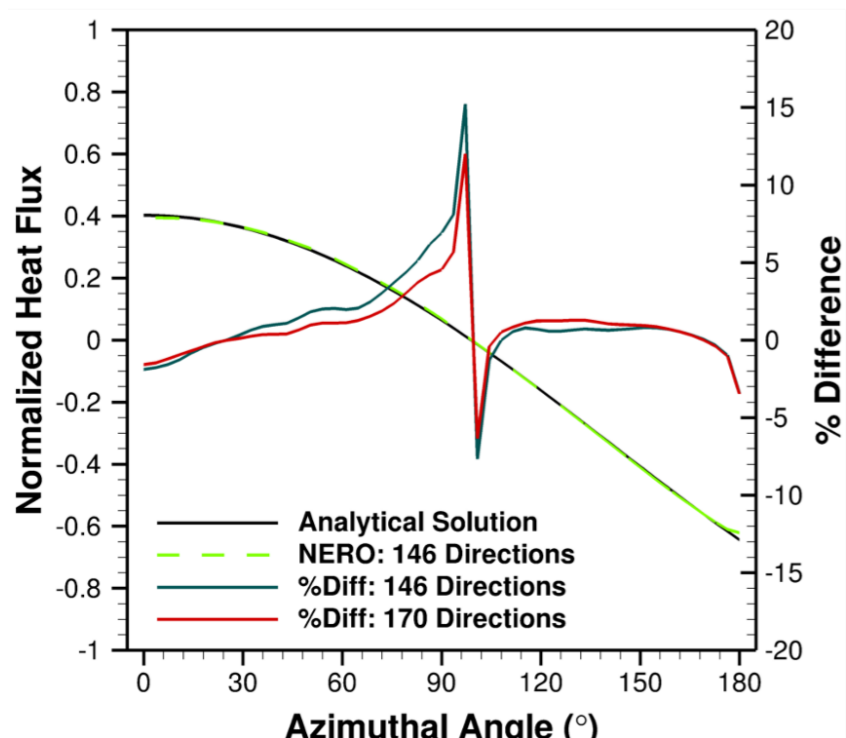


Figure 2. Verification on a self-radiating hollow cylinder.

Coupling with Ares

Ares is a multi-physics platform for coupling distinct domains of entry systems modeling. In this context, Ares manages the transfer of information and the time-integration of the coupled radiation-material response system. Since the radiative emission is a function of wall temperature, it is important to model the former accurately with material response. Net enclosure contribution is split from total radiative heat flux (shock layer radiation) and added to the material response energy balance. Once the wall temperature is updated from the material response solver, the new enclosure contribution is computed in NERO. Thus, the enclosure terms are always lagged in the energy balance, as described in Eq. 1.

$$q_{\text{cond}}^n = \alpha(q_{\text{rad,shock}} + q(T_w^{n-1})_{\text{rad,encl}}) - \epsilon\sigma(T_w^n)^4 \quad (1)$$

Application to Dragonfly

A conceptual Dragonfly aeroshell design would include a feature of the shoulder tile referred to as the *tooth*, where TPS would shield a seal at the conjunction of the heat-shield and backshell. Though the seal is protected from the high enthalpy flow, the high heat transfer through the TPS increases the temperature of the surface directly above the seal, emitting radiation onto the latter. A time-accurate material response simulation was conducted over the 1000 seconds of entry time with the enclosure radiation being updated at a frequency of 0.1 seconds. The wall temperature and radiative heat flux due to re-emission and reflection are shown at a snapshot in time in Fig. 3.

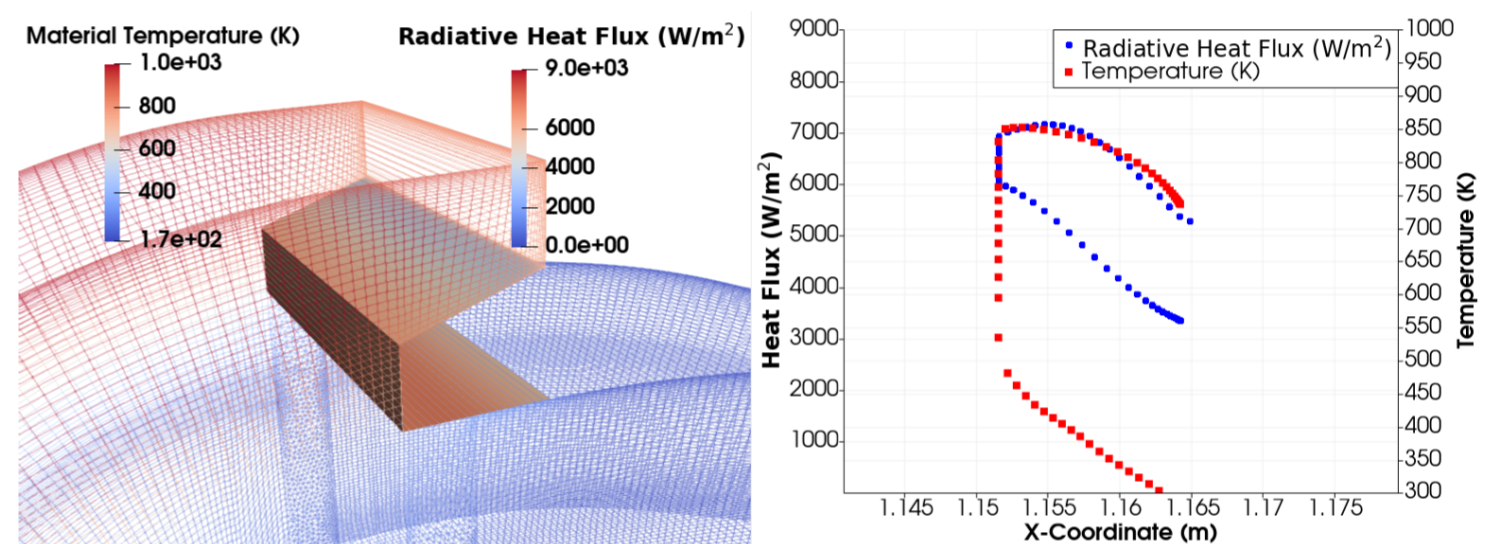


Figure 3. Enclosure radiation on the Dragonfly tooth.

Application to MMOD

Another application where enclosure radiation can be important is in cavities. Of concern are cavities resultant from impacts from micro-meteoroids and orbital debris (MMOD). Here, a cavity was placed on a shear test article in an arc-jet test. The total radiative heat flux was calculated and is shown in Fig. 4.

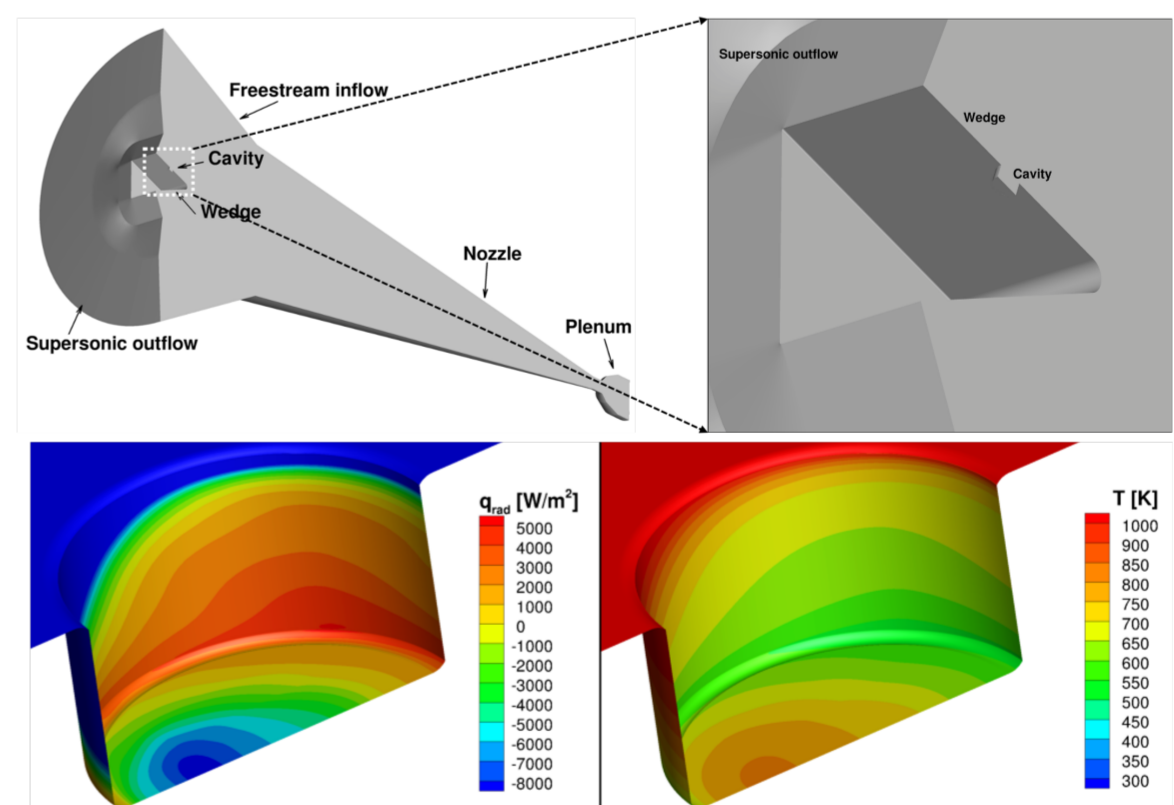


Figure 4. Radiative heat flux in a cavity in arc-jet.

References

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