Computational Modeling of Flows Bridging Continuum to Rarefied Regimes

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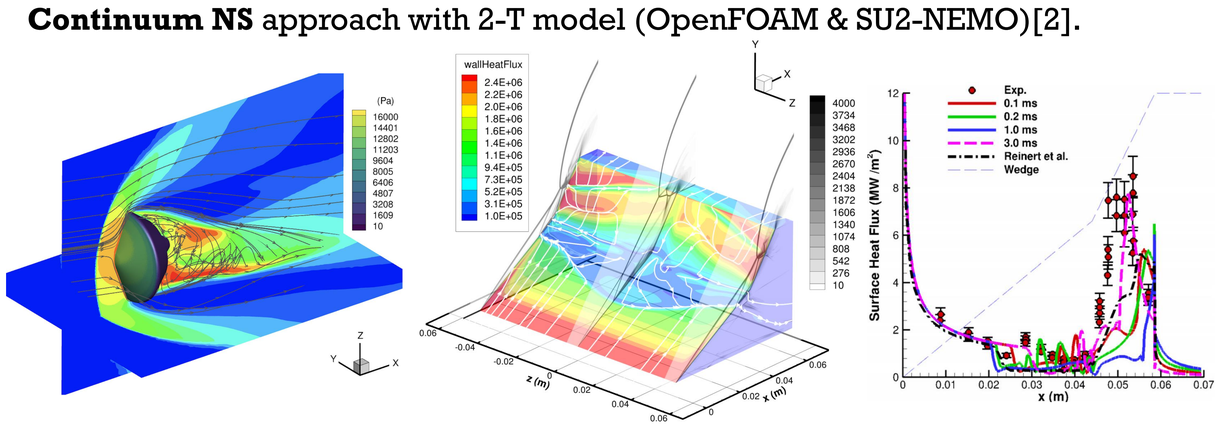
HYPERSONIC FLOWS

- Hypersonic reacting flows at Mach > 5 can be modeled using:

  Kinetic Approach: high-fidelity direct simulation Monte Carlo (DSMC) method, an approach to emulate the Boltzmann Equation is used [1].

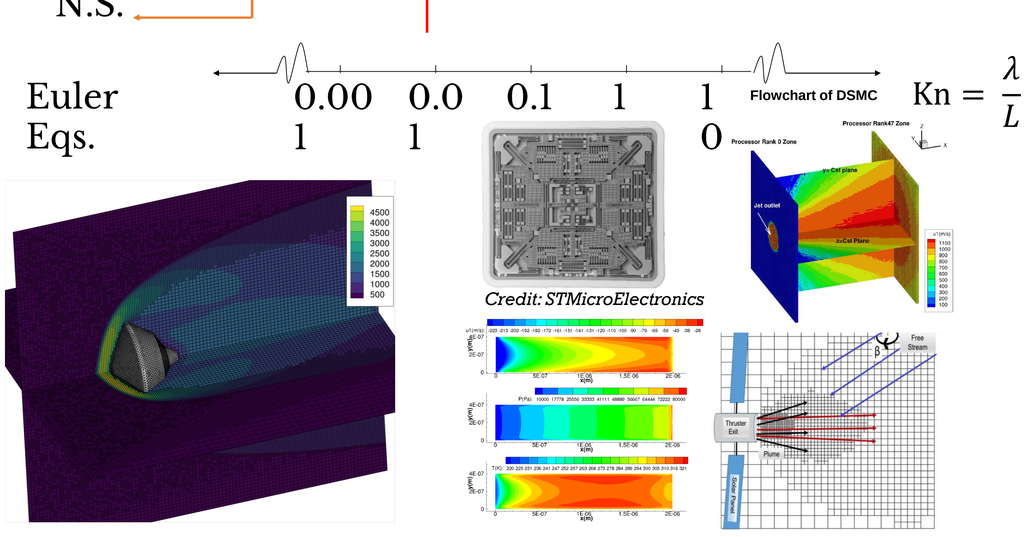
  Continuum NS approach with 2-T model (OpenFOAM & SU2-NEMO)[2].



Re-entry modeling using SU2-NEMO (right), Mach 7 flow over a double wedge and its time variation of surface heating (left),

RAREFIED FLOWS

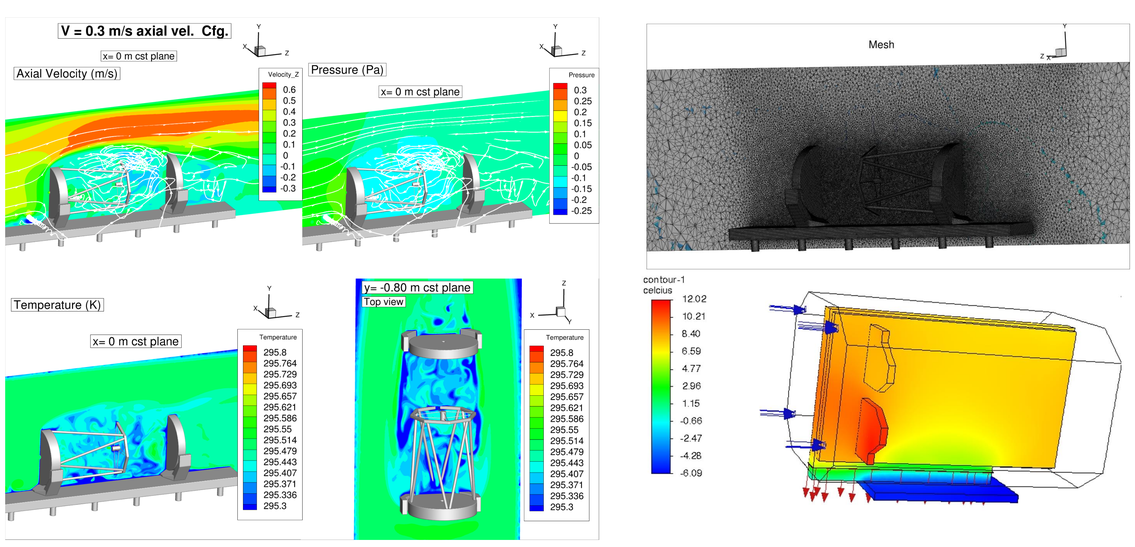
- Large Knudsen number flows (Kn > 0.01). These flows occur:
  - at low-density (space applications) [5] or
  - in very narrow channels (MEMS applications).
- DSMC is commonly used [3-4].



Applications of DSMC: Re-entry (left), MEMS flow modeling (middle), electric propulsion (right).

HEAT TRANSFER AT LOW SPEEDS

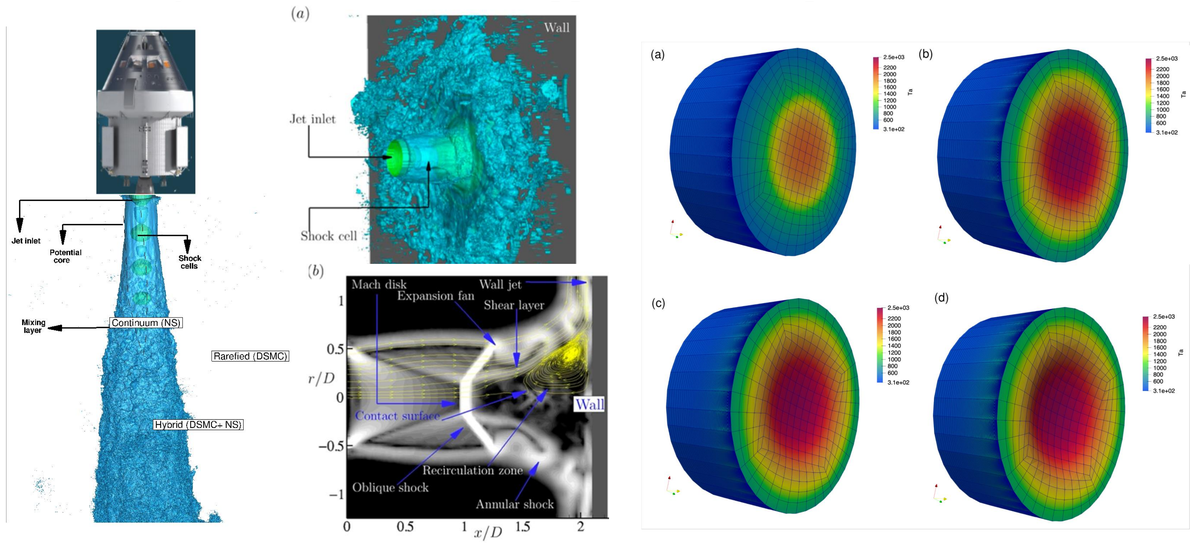
- Continuum low-speed heat transfer can be modeled using continuum solvers.
- High-fidelity turbulent modeling approaches are used.



Flows over an optical system

MULTISCALE / PHASE SOLVERS

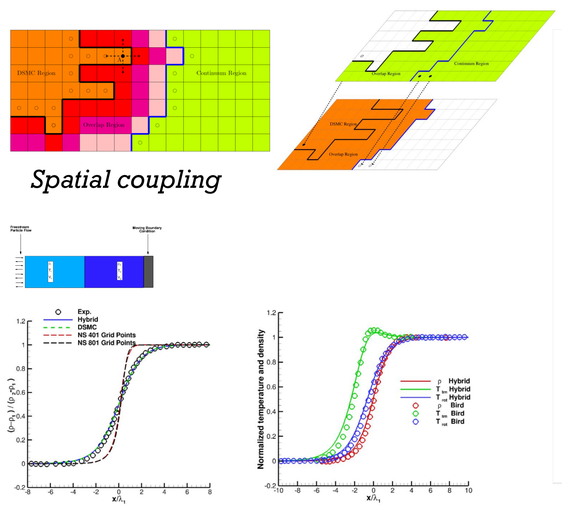
- In-house open-source software tools are being developed to model jet impinging during landing over the Moon.
- Parallel hybrid continuum-kinetic approaches are implemented.

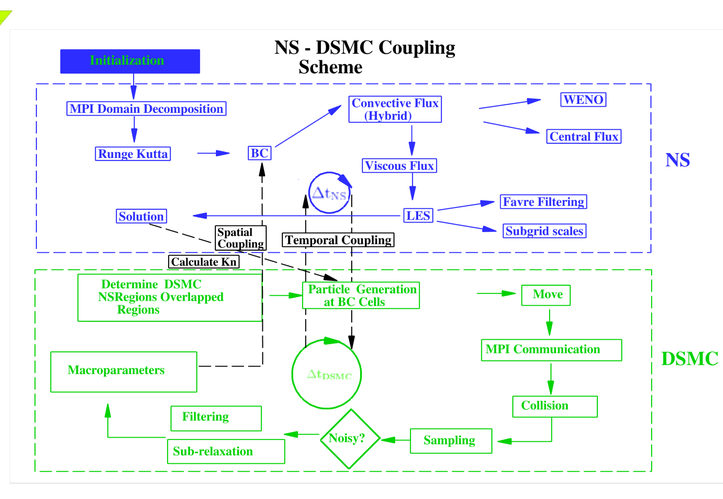


Multiphase flow modeling: Jet-expansion (right), surface degradation during re-entries (left).

PARALLEL SCIENTIFIC SOFTWARE DEVELOPMENT

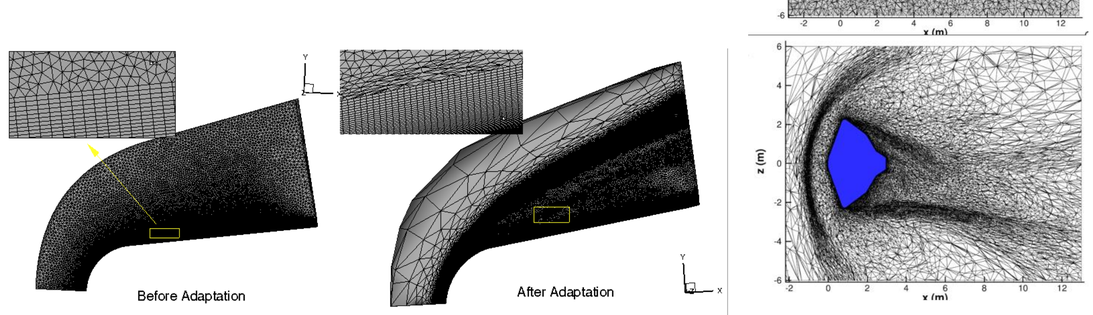
- A parallel multispecies hybrid software is being developed.
- Message Passing Interface (MPI) is used for communication.





GRID GENERATION AND ADAPTATION

- Open-source GMSH software is used to generate meshes for subsonic to hypersonic applications .
- The pyAMG library is used to capture all gradients efficiently.
- Structured, unstructured, hybrid grids are used.



REFERENCES

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[3] Tumuklu O. *et al.,* AIAA-Journal, 54, 12 (2016).

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OpenFOAM® Gmsh SU2 code NEQAIR SPARTA PATO Mutation++ POROUS MATERIAL ANALYSIS TOOLBOX BASED ON OPENFOAM