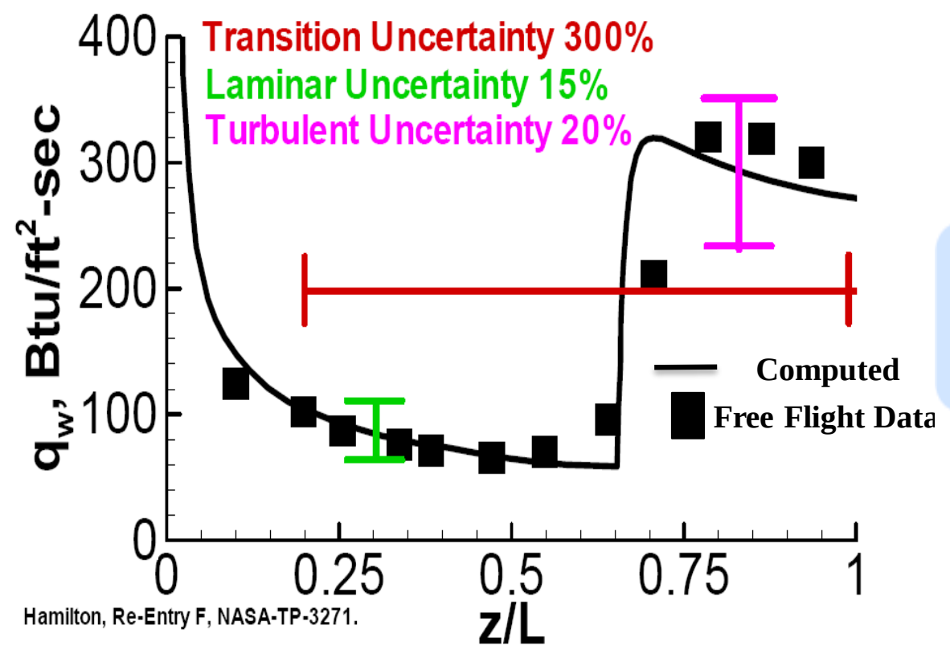
Towards Exascale DNS Solver for Hypersonic Boundary-Layer Receptivity to Solid Particulates

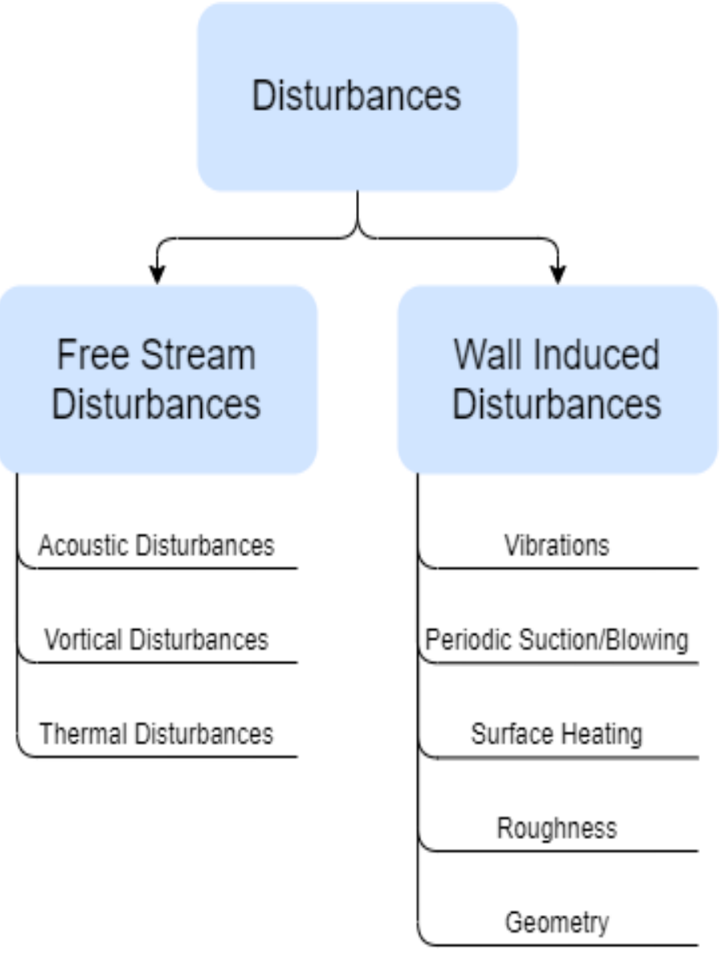
Furkan Oz[1] and Kursat Kara[1]
[1]Mechanical and Aerospace Engineering, OSU

Objective

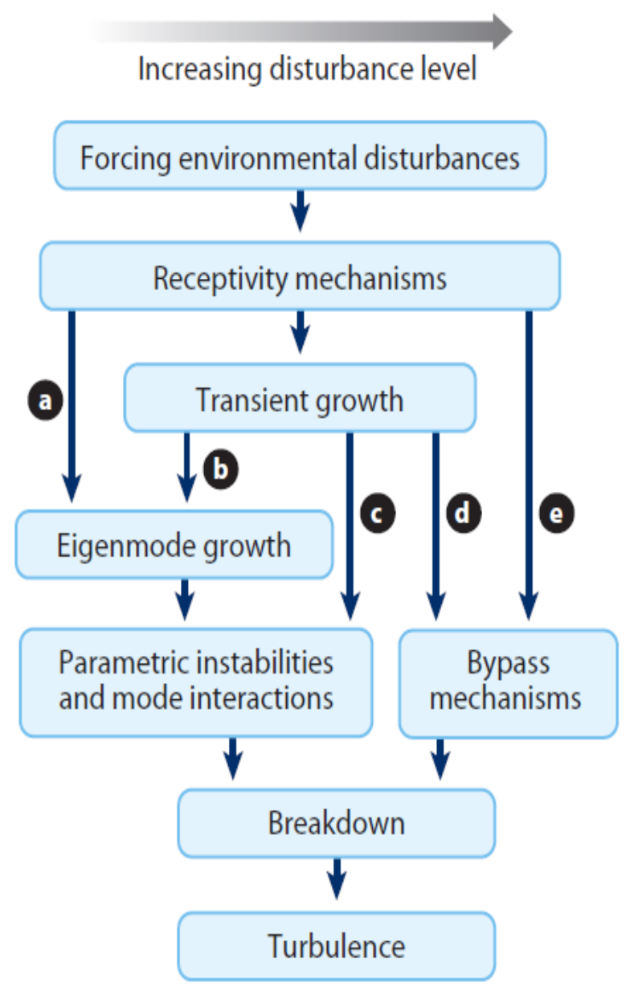
The prediction of hypersonic boundary-layer transition location from a laminar to a turbulent state is vital to the development of hypersonic vehicles because of the first-order impact on aerodynamic heating, drag force, engine performance, and vehicle operation.



Schneider, Prog. in Aerospace Sciences, 40, 2004

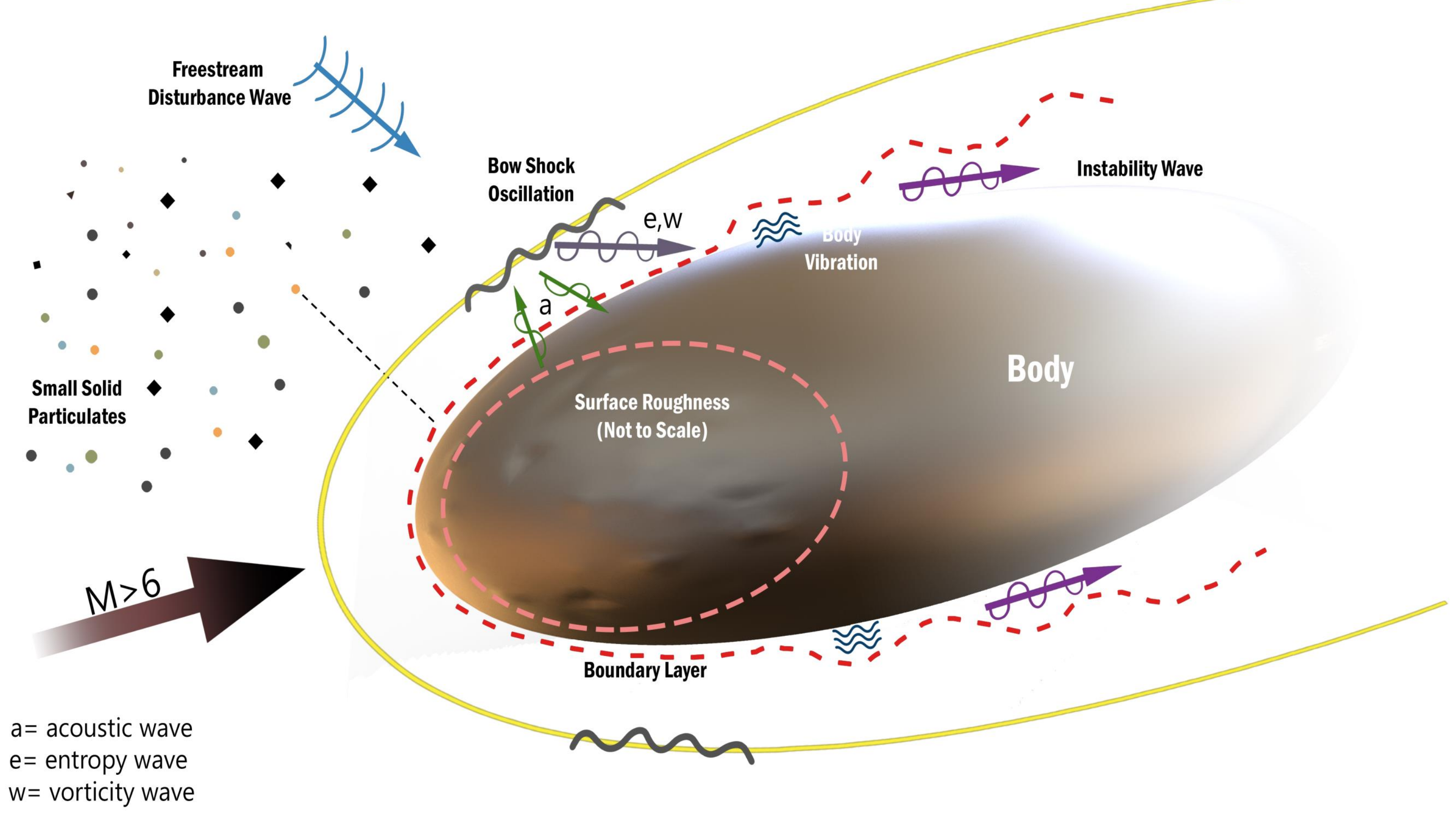


Fedorov (2003)



Reshotko (2008)

The small particulates that enter the boundary layer causes nonlinear disturbances as a results instability waves which grow in downstream occur in the boundary layer. In this research, dynamic interaction of particulates, particulate-induced vortical disturbances, acoustic waves, and surface roughness with boundary-layer from the first principles will be investigated with physics-based DNS tool.



a= acoustic wave
e= entropy wave
w= vorticity wave

Preliminary Considerations

- Particulate size is modelled as 10 µm.
- Particulates density is modelled as 10^3 kg m^{-3}.
- Process is assumed adiabatic.
- We assumed that collision does not change surface roughness.
- Particulate is assumed as spherical.

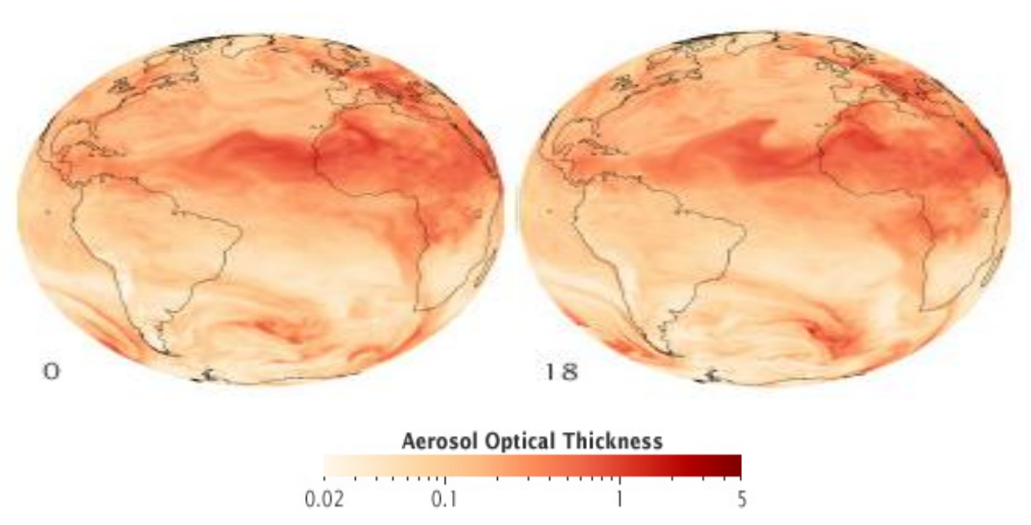
Summary

In order to investigate the effect of the particulates that are suspended in the air, particulate and fluid domain are modelled as shown. Steady hypersonic flow is solved with parallel DNS solver. Collision location of the particulate with the body is calculated by using mean flow solution. For further studies, parallel 2D DNS solver will be extended to 3D exascale DNS solver to investigate the interaction of the particulate with the flow. Effect of particulate number and size are also will be investigated.

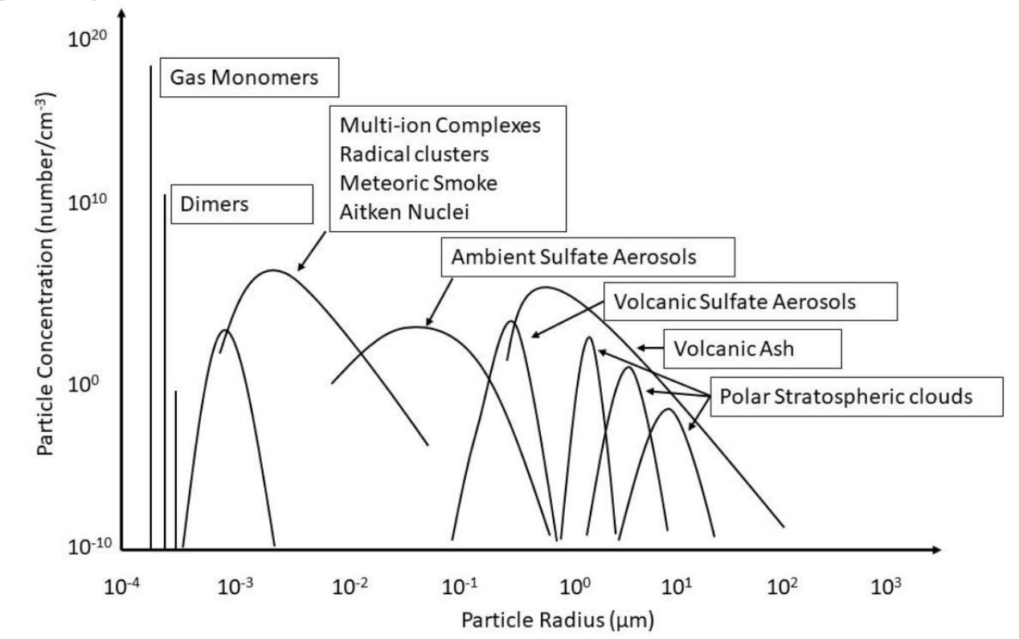
Solid Particulates

Solid particulates that are suspended in the air has a great impact on this boundary-layer transition[1]. Volcanic and other terrestrial dust, cosmic dust and ice clouds can be given as example to source of solid particulates[2, 3].

Desert dust, smoke from forest fires, and volcanic ash are natural sources of aerosols. (Photographs copyright (left to right) Western Sahara Project, Vox, and Maan de Ocampo-Ignacio.)



NASA maps that show particulate movement in the atmosphere by Pete Colarco and Robert Simmon, based on GEOS-5 model data.



Particulate size and concentration distribution in the middle atmosphere. [Turco (1992)]

References

1. Bushnell, D. 1990, Notes on initial disturbance fields for the transition problem. In Instability and Transition (ed. M. Y. Hussaini & R. G. Voigt), pp. 217–232. Springer.
2. Turco, R. P. 1992 Upper-atmosphere aerosols: properties and natural cycles. Chapter 3D in: The Atmospheric Effects of Stratospheric Aircraft: A First Program Report, United States, no. 92-19124, pp. 63–91.
3. Guide to Global Aerosol Models (GAM), AIAA G-065-1999. Available at doi:10.2514/4.473692.001.
4. Kara, K., Balakumar, P., & Kandil, O. A. 2011. Effects of Nose Bluntness on Hypersonic Boundary-Layer Receptivity and Stability over Cones. AIAA Journal, 49(12), 2593–2606. doi: 10.2514/1.j050032

Results

Compressible, axisymmetric Navier-Stokes equations that is taken from Kara (2011) is solved with flow condition giving in the Table 1.

$$\frac{\partial Q}{\partial t}+\frac{\partial F}{\partial x}+\frac{\partial G}{\partial y}=\frac{\partial F_v}{\partial x}+\frac{\partial G_v}{\partial y}+S$$

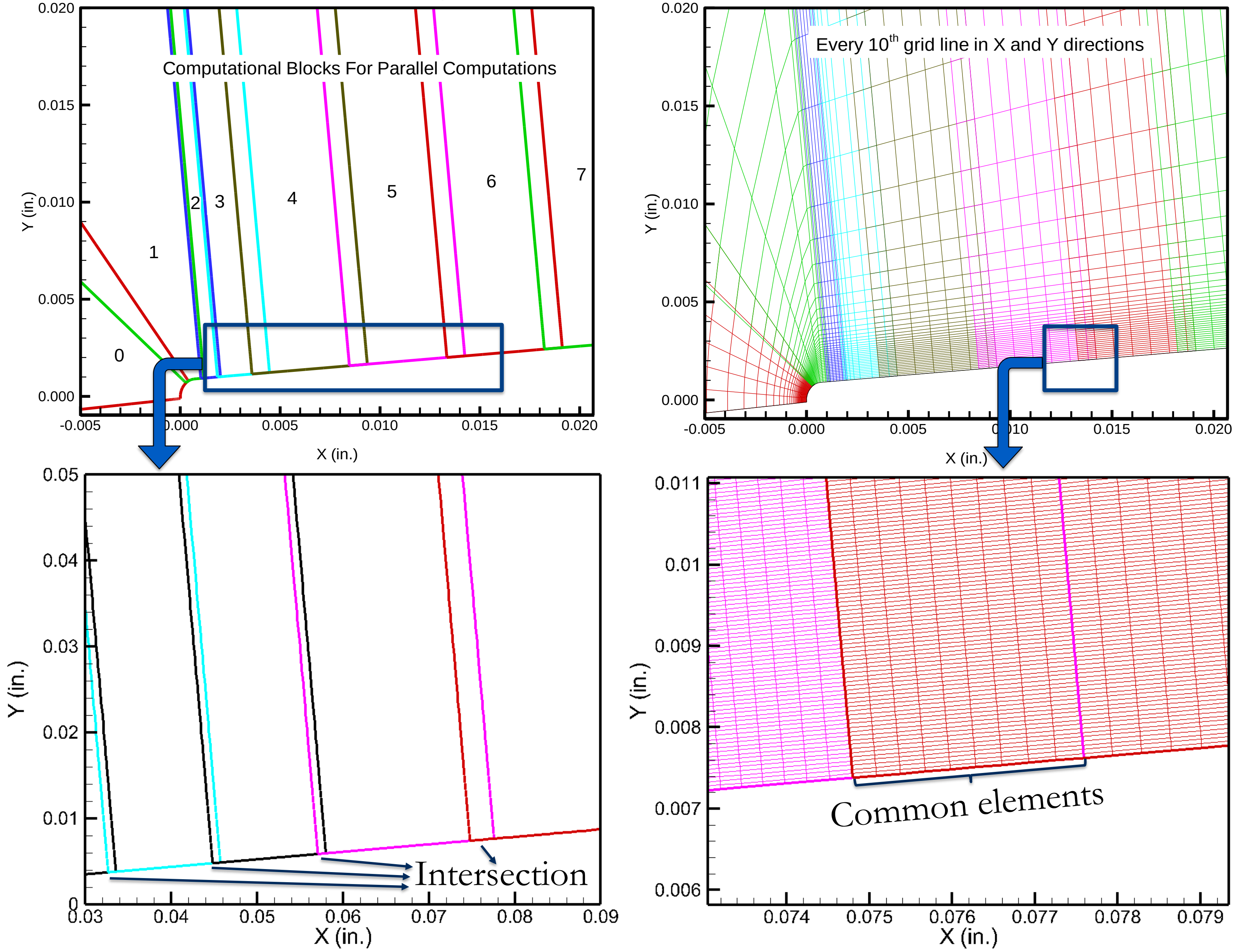
$$\mathrm{Q}=\begin{bmatrix}\rho\\ \rho u\\ \rho v\\ \rho E\end{bmatrix}\qquad \mathrm{F}=\begin{bmatrix}\rho u\\ \rho u^2+p\\ \rho uv\\ (\rho E+p)u\end{bmatrix}\qquad \mathrm{G}=\begin{bmatrix}\rho v\\ \rho uv\\ \rho v^2+p\\ (\rho E+p)v\end{bmatrix}$$

$$\mathrm{F_v}=\begin{bmatrix}0\\ \tau_{xx}\\ \tau_{xy}\\ u\tau_{xx}+v\tau_{xy}-qx\end{bmatrix}\qquad \mathrm{G_v}=\begin{bmatrix}0\\ \tau_{yx}\\ \tau_{yy}\\ u\tau_{yx}+v\tau_{yy}-qy\end{bmatrix}$$

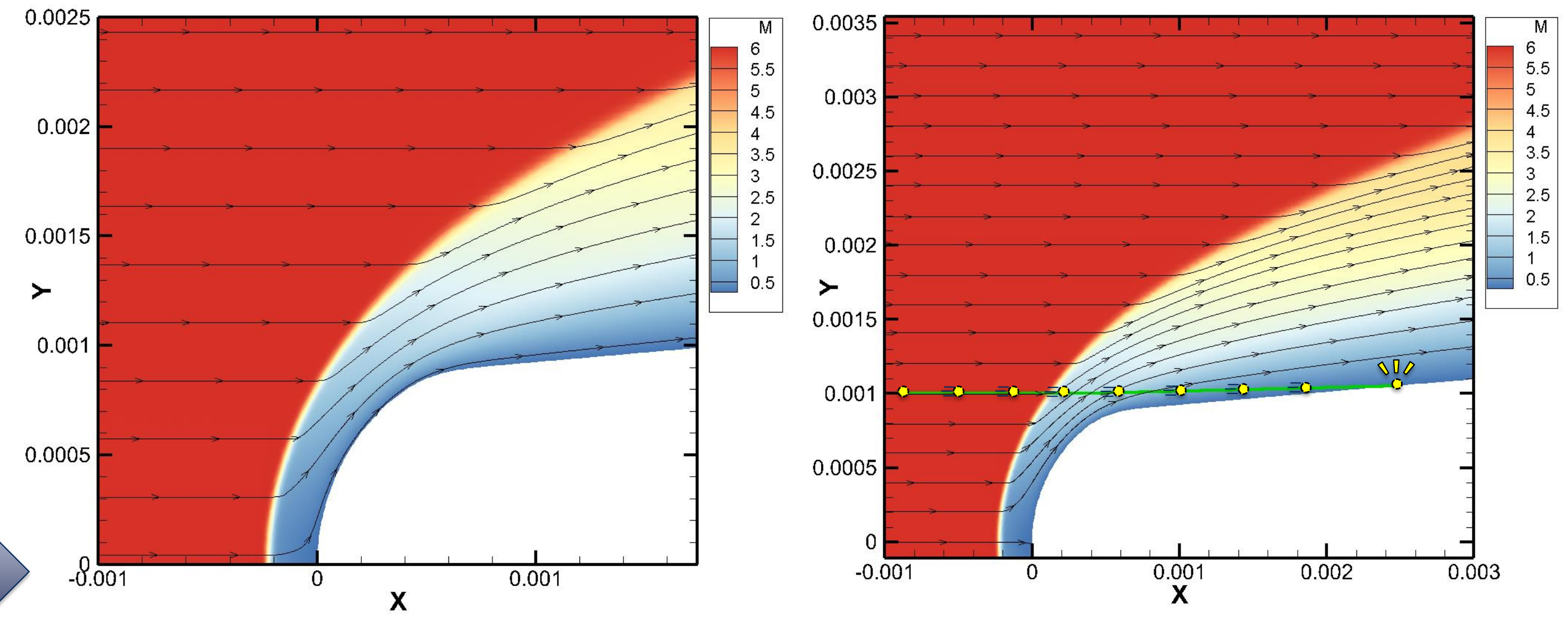
Table 1. Flow parameters for Horvath(2002)'s wind tunnel model.

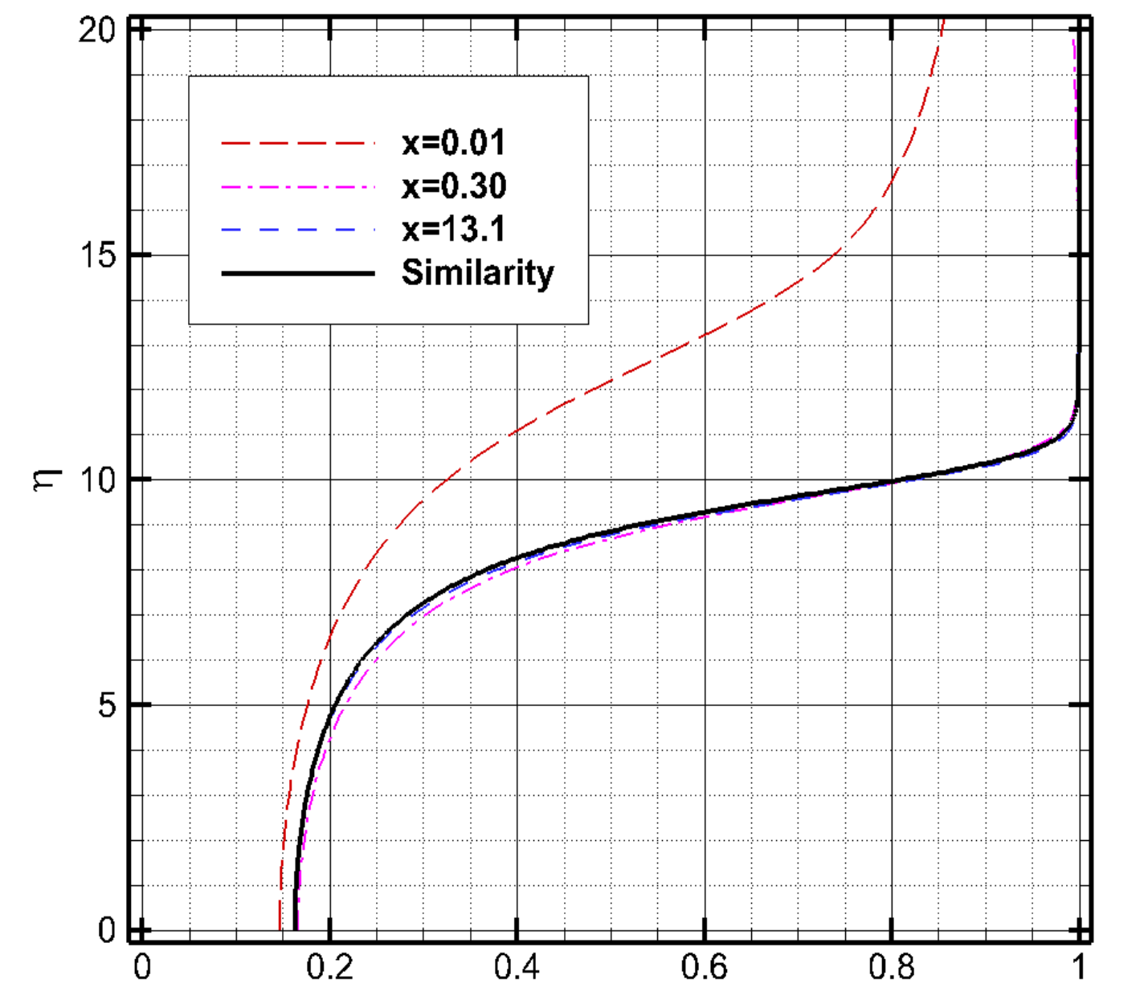
Freestream	Mach Number	M_∞	6.0
	Unit Reynolds Number	Re_∞	7.8x10^6 /ft
	Density	ρ_∞	7.059x10^{-3} lbm/ft^3
	Velocity	U_∞	3140.21 ft/s
Reservoir Pressure		P_0	475psi
Reservoir Temperature		T_0	475 °F

Grid is divided into 32 pieces that are separated to 32 core. In order to increase speed of the code by preventing communication between cores, common elements that are necessary for 5th order WENO are used.



5th order WENO for spatial discretization and a 3rd order Runge-Kutta for time integration. Verification is done with similarity solution. Collision location of small particulate in the mean flow is calculated.





Time Step	Collision Point Location(x,y)
Initial Point	(-1.000e-02, 1.0000e-03)
Δt=500e-7	(2.4966e-03, 1.0550e-03)
Δt=10e-7	(2.4508e-03, 1.0510e-03)
Δt=5e-7	(2.4514e-03, 1.0511e-03)
Δt=1e-7	(2.4514e-03, 1.0511e-03)

Contact Information: foz@okstate.edu, kursat.kara@okstate.edu