Computational Flow Field in Energy Efficient Engine (EEE)

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Motivation

- Future propulsion systems will be of increasingly higher bypass ratio from larger fans combined with much smaller cores
- Important to understand core engine component interactions, such as <u>combustor-turbine interactions</u>

From "**Deposition With Hot Streaks in an Uncooled Turbine Vane Passage**", B. Casaday, et al J. Turbomach, 2013 Vol. 136 (Permission from Prof. Bons and thanks to Dr. Mike Dunn @ OSU)

- Designing high-pressure turbines (HPTs) for *peak* temperatures at the combustor exit ➔ More cooling air ➔Less cycle efficiency
- Designing HPTs for the *mean* exit-temperature at the combustor exit ➔ More local hot spots (hot streaks) ➔ Less gas turbine durability
- CFD should give some design guidelines

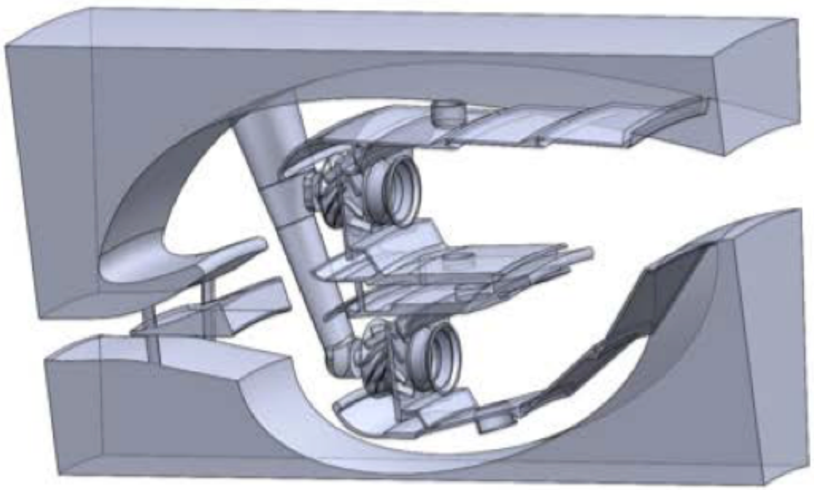
Features of Open National Combustion Code (OpenNCC)

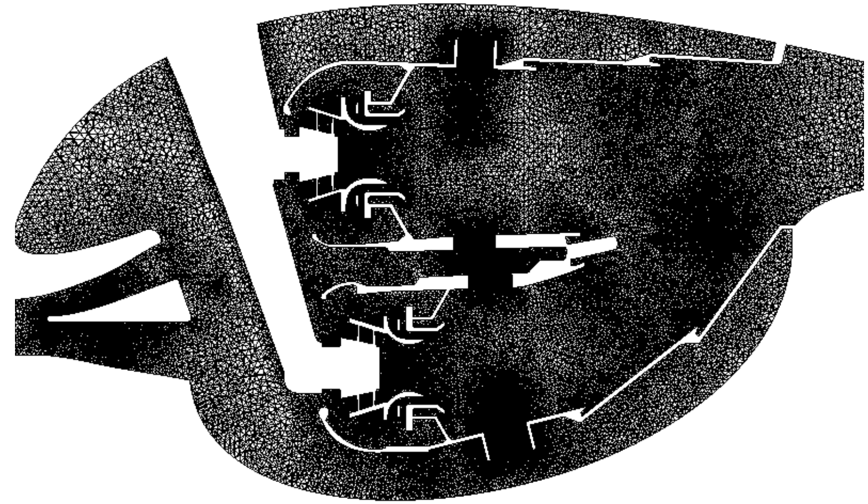
- OpenNCC is the releasable version of the National Combustion Code (NCC), which has been continuously updated for more than two decades at NASA Glenn Research Center (GRC)
- Main Features
  - ✓ Numerics: Jameson-Schmidt-Turkel (JST) scheme and Roe's upwind scheme, and *advection upstream splitting method (AUSM)*[1-3]
  - ✓ Turbulence: Cubic non-linear k-ε[4] model with the wall function, Low-Re model
  - ✓ Combustion: Reduced chemical kinetic, low dimensional manifold, Linear Eddy Model (LEM)[5]
  - ✓ Spray: Lagrangian liquid phase model[6-8]
  - ✓ Other features: Low-Mach preconditioning, *transition model*[9], unstructured mesh, adaptive mesh refinement (AMR)[10], massively parallel computing (with almost perfectly linear scalability achieved for non-spray cases up to 4000 central processing units)

Selected referece

(1) Liou, M.-S. and Steen, C. J., Journal of Computational Physics, Vol. 107, (1993)
(2-3) Liou, M.-S., Journal of Computational Physics, Vol. 129, 1996) and (2006)
(4) Shih, T.-H., Chen, K.-H., and Liu, N.-S., AIAA 1998-35684 (1998).
(5) Alan R. Kerstein, Combustion Science and Technology, Vol 60 (1988)
(6-8) Raju, M., NASA/CR97-206240 (1997), NASA/CR1998-20401 (1998) and NASA/CR2004-212958 (2004).
(9) Liou, W. and Shih, T.-H., No. NASA/CR-2000-209923 (2000).
(10) Wey, T. and Liu, N.-S., AIAA 2014-1385 (2014).

Energy Efficient Engine (E^3) – GE design, 80s -





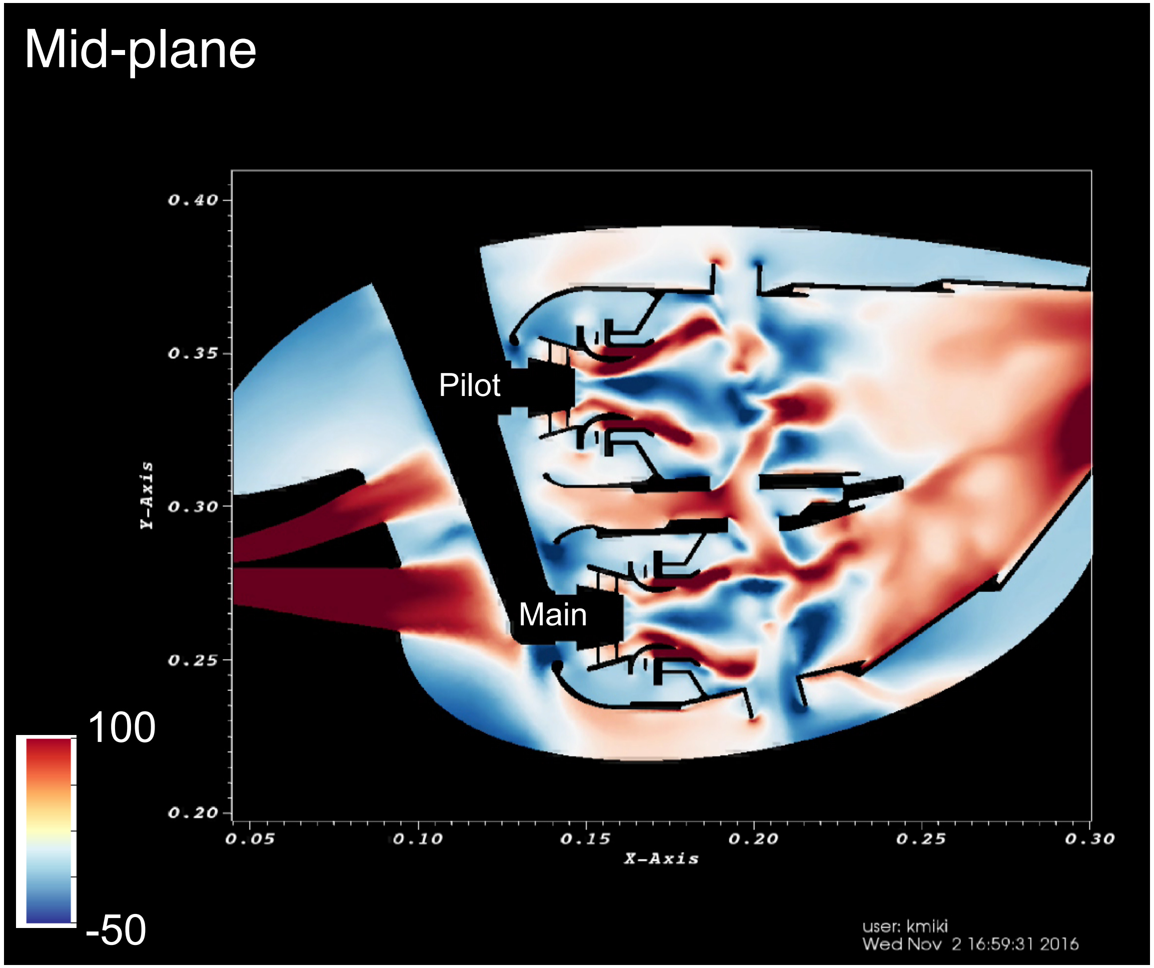
	Numerics	Steady?	Spray	Fuel	Chemistry
Case 1	JST/AUSM	Yes	Gas	C12H23	one-step
Case 2	JST/AUSM	Yes	Liquid	C11H21	14 species-18 reactions
Case 3	JST/AUSM	No	Liquid	C11H21	14 species-18 reactions

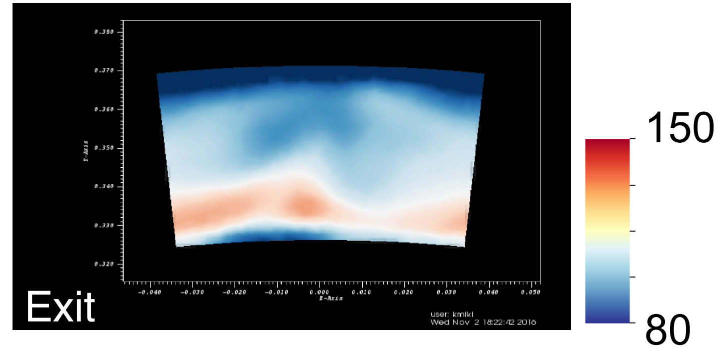
- One-cup (12 degree) E^3 geometry(1) is considered
- Tetrahedral mesh (~9.5M) is generated by Cubit (AMR is off)
- Used 960 processors of Pleiades at NASA Advanced Supercomputing facility
- Non-linear k-ε model and finite-rate chemistry
- Taken into consideration is the simulated sea level takeoff condition (SLTO)

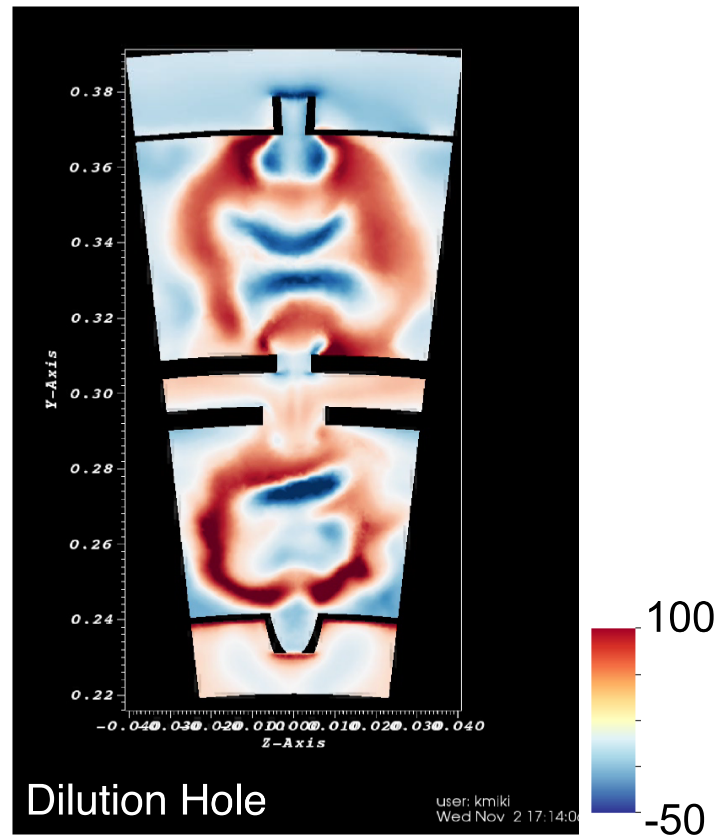
	P3 [atm]	T3 [K]	W3 [kg/s]	Wf_{total} [kg/s]	f/a	Wf_{pilot}/Wf_{total}	T_{fuel} [K]
SLTO	2.52	720	0.26	0.00364	0.014	0.5	520

(1) Burrus, D. L., et al, No. NASA/CR-1984-168301, (1984)

Unsteady Flow Fields (axial velocity)



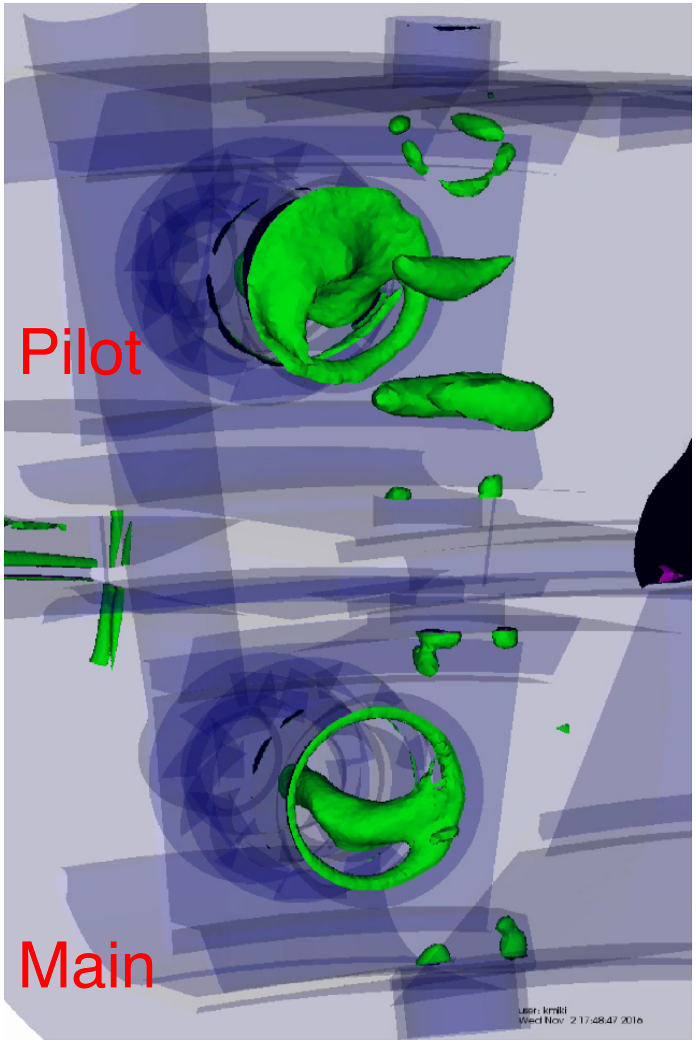




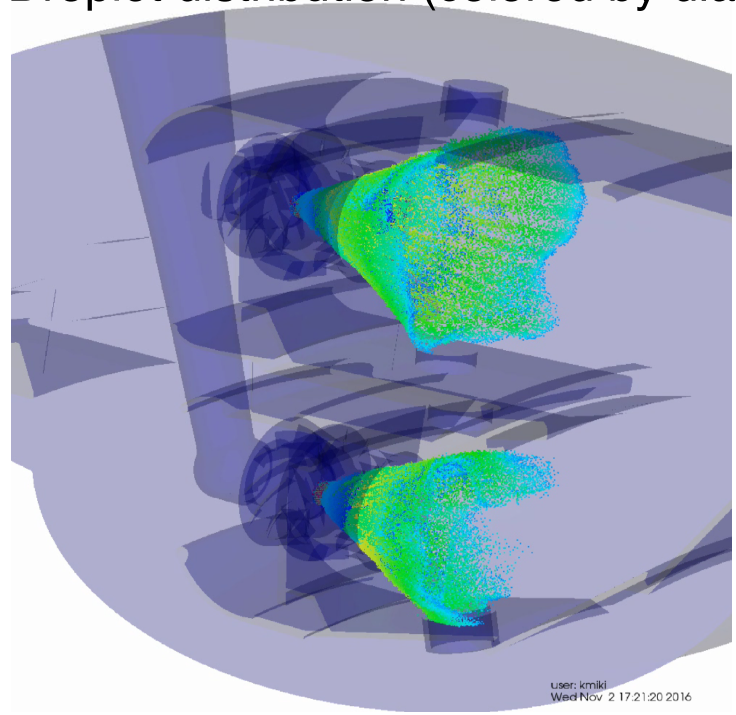
- Dilution airflow and swirling airflow interact and oscillate back and forth.
- There is a recirculation zone at the top of the dilution hole, enhancing the oscillation.

Processing Vortex Core (PVC)

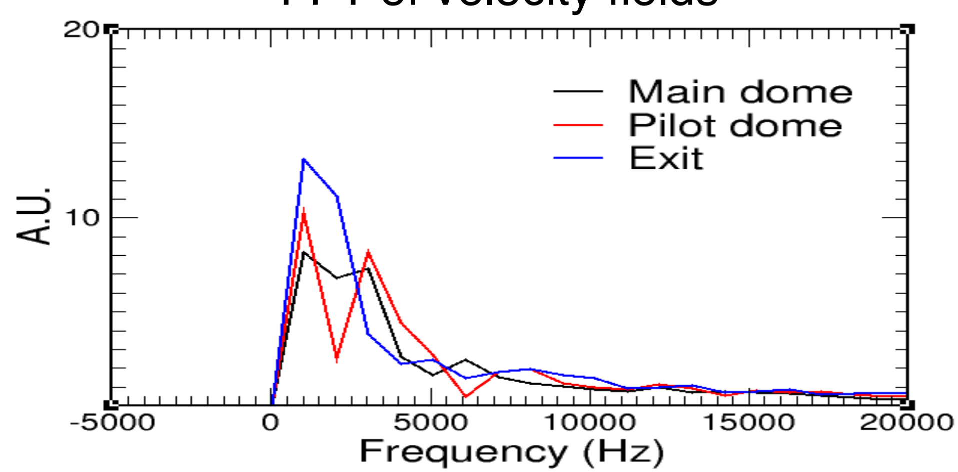
Pressure iso-surface (245K Pa)



Droplet distribution (colored by dia.)

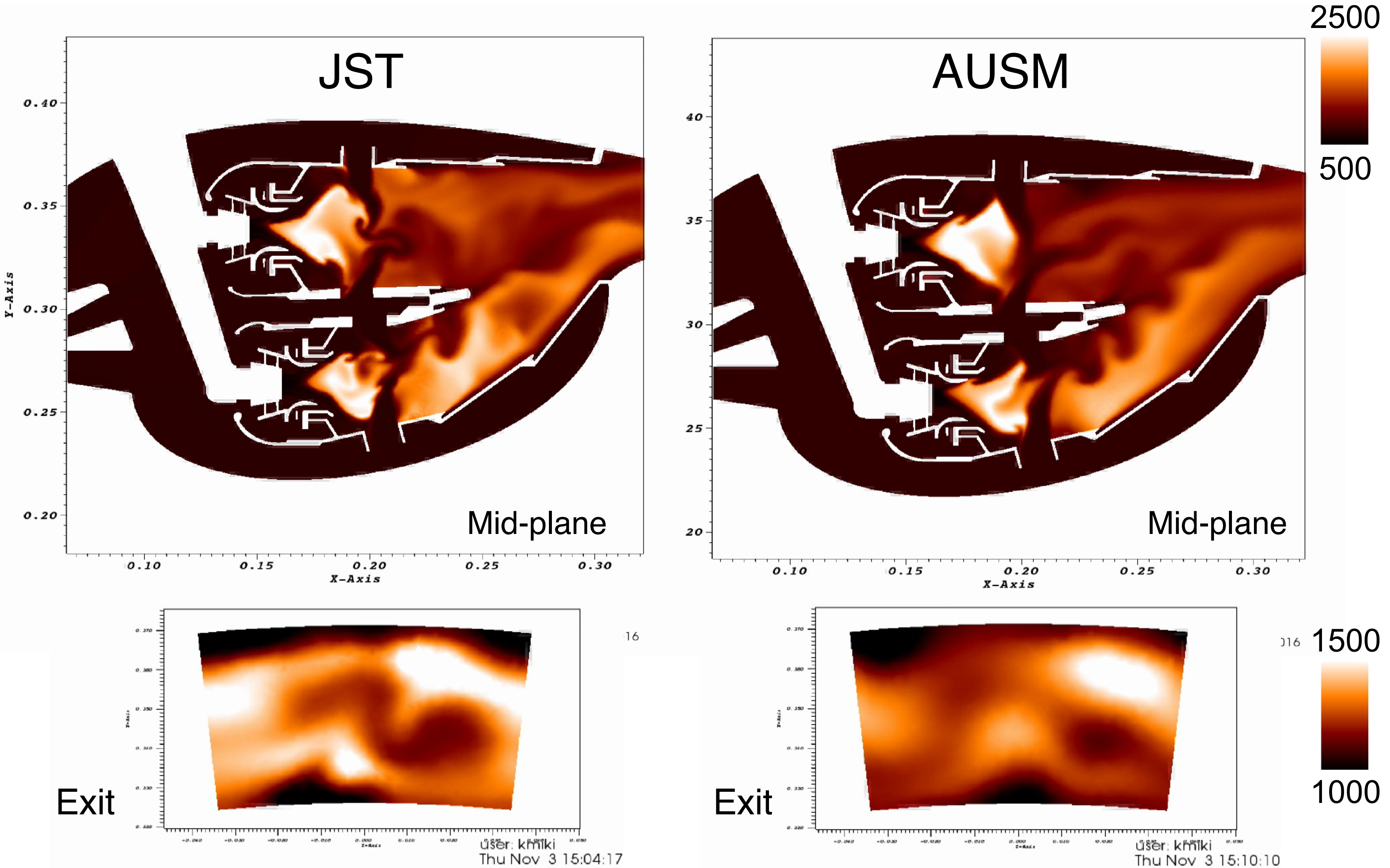


FFT of velocity fields



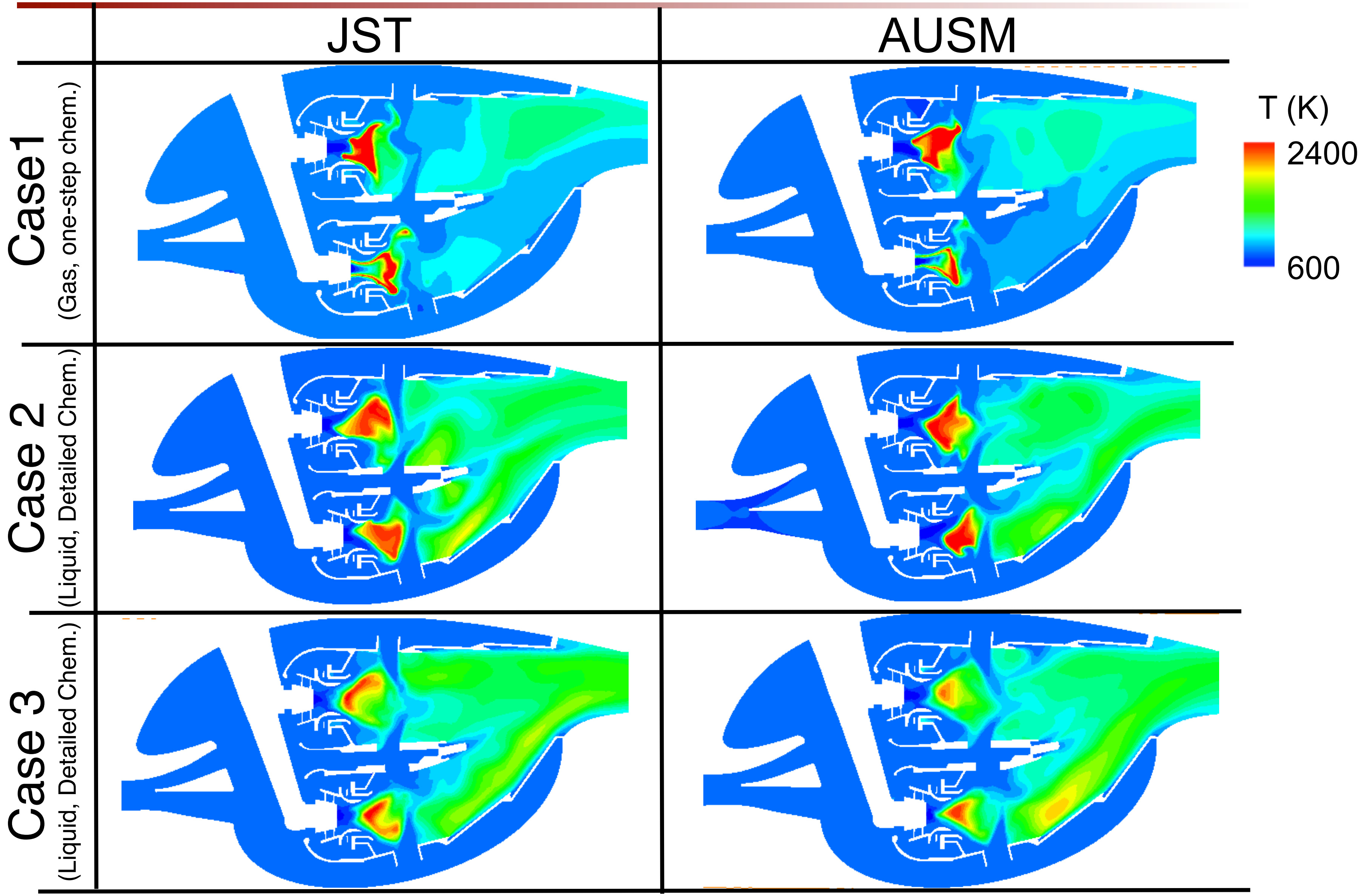
- PVC greatly impacts on the particle motion and the combustion dynamics.

Temperature Fields



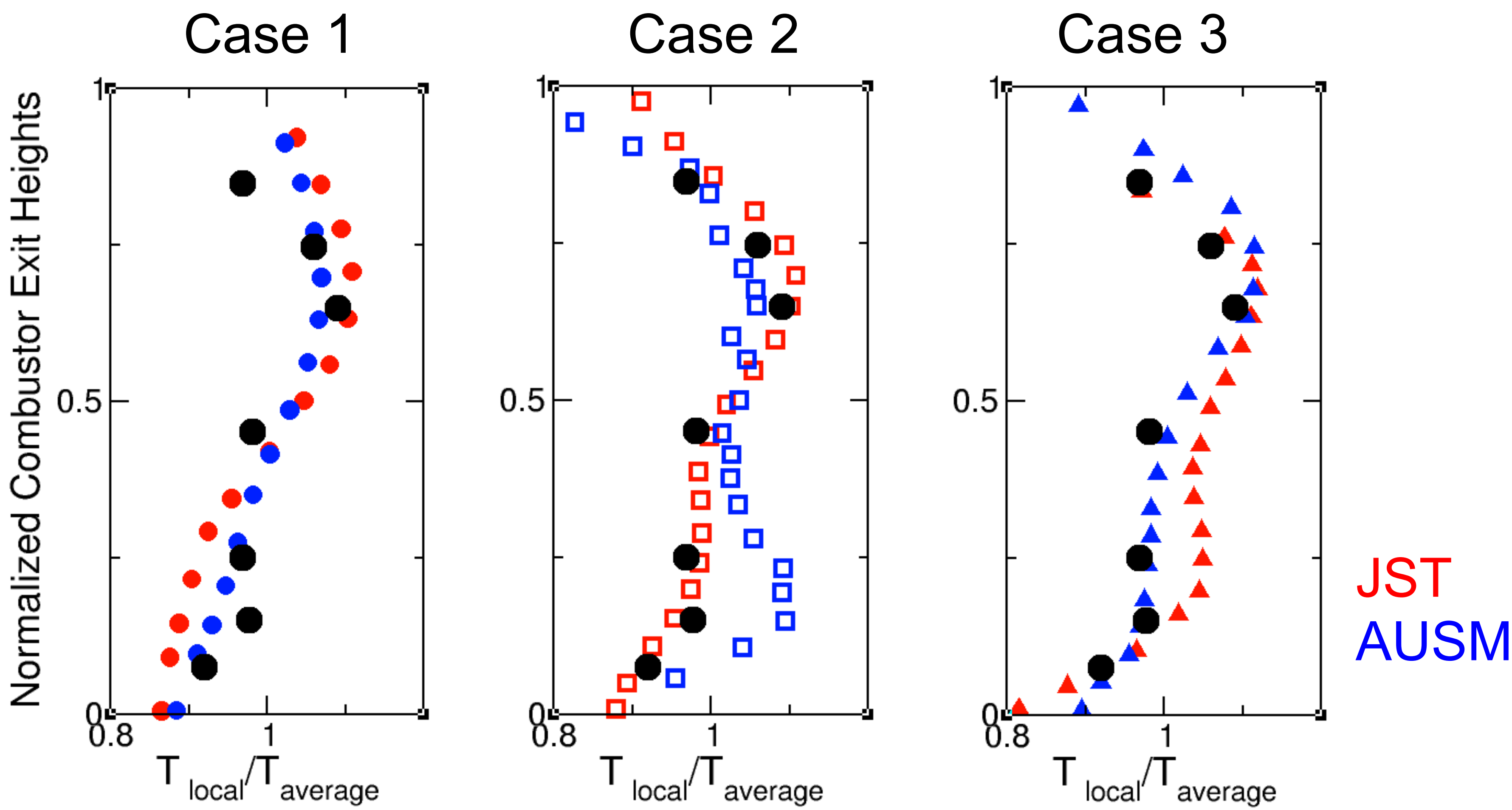
- Temperature field is not uniform at the combustor exit and lots of hot/cold “spots” .

Averaged Temperature Profiles



- The flame is not attached to both fuel domes using the liquid spray.

Exit Temperature Profile and Conclusions



- JST (red) and AUSM (blue) shows some difference, especially near the bottom wall.
- Bi-modal distribution is successfully captured by using the liquid-spray injection.
- We are planning to turn on the adaptive mesh refinement, and turbulence-chemistry interaction (e.g., LEM), and consider the combustor-turbine interaction.

Thank you!

Acknowledgement

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