Parameter Analysis and Contrail Detection of Aircraft Engine Simulations

Nafiul Nipu, Carla Floricel, Negar Naghashzadeh, Roberto Paoli, G. Elisabeta Marai
University of Illinois at Chicago

INTRODUCTION

Aircraft engines emit particulates that alter the chemical composition of the atmosphere and perturb the Earth's radiation budget by creating additional ice clouds in the form of condensation trails called contrails.

We propose a multi-scale visual computing system that will assist in defining contrail features with parameter analysis for computationally intensive and high performance computing computer-generated aircraft engine simulations.

Our multi-scale visual system seeks to help in the identification of the formation and evolution of contrails and in the identification of contrail-related spatial features from the simulation workflow.

OBJECTIVE

Data:

- A single simulation run can take up to several days and requires high-performance computing.
- The dataset contains 19 computer-generated aircraft engine particle simulations (>100GB).
- Each simulation is run with different input parameters and boundary conditions.
- Each ensemble member consists of multiple time steps.
- Each time step has multiple attributes of the engine particles (e.g. position, temperature, diameter, etc).

Design: The interface consists of three main views –

- **Input and Output Parameters View** supports summarization and comparison for all ensemble members.
- **3D Airplane Engine Projection View** shows volumetric 3D view of two ensemble members over time.
- **Ensemble Member Similarities View** presents an overview of correlation between simulation runs.

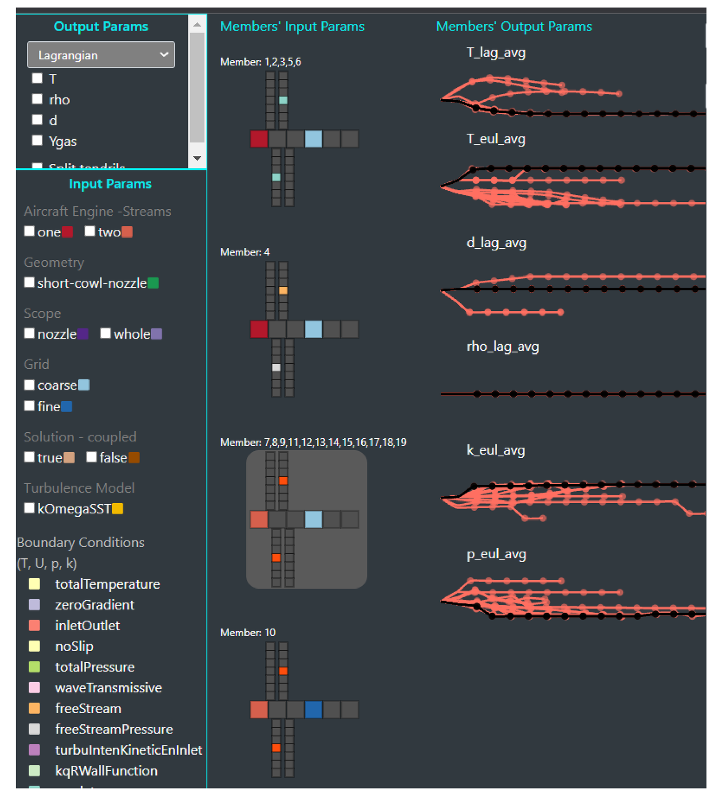

Fig 1: Input and Output Parameters View, consisting of a filtering panel (left), a custom encoding for grouping members based on the simulation input parameters (middle), and filament plots [1] for grouping output parameters (right).

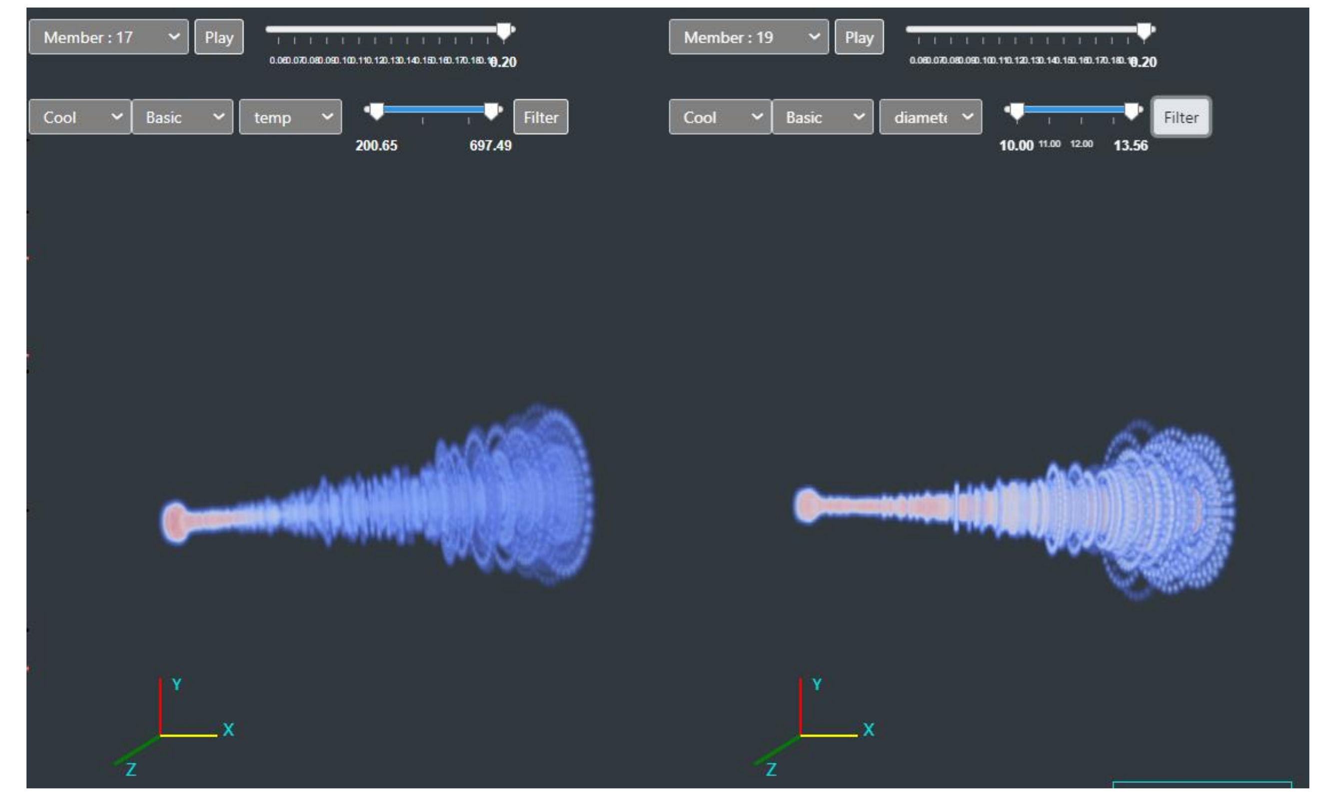

Fig 2: 3D Airplane Engine Projection View, showing the evolution of engine particles over time, for two ensemble members, using direct volume rendering. Particles are colored according to temperature (left) and diameter (right). An animation can also be played to visualize the evolution of particles in a single simulation.

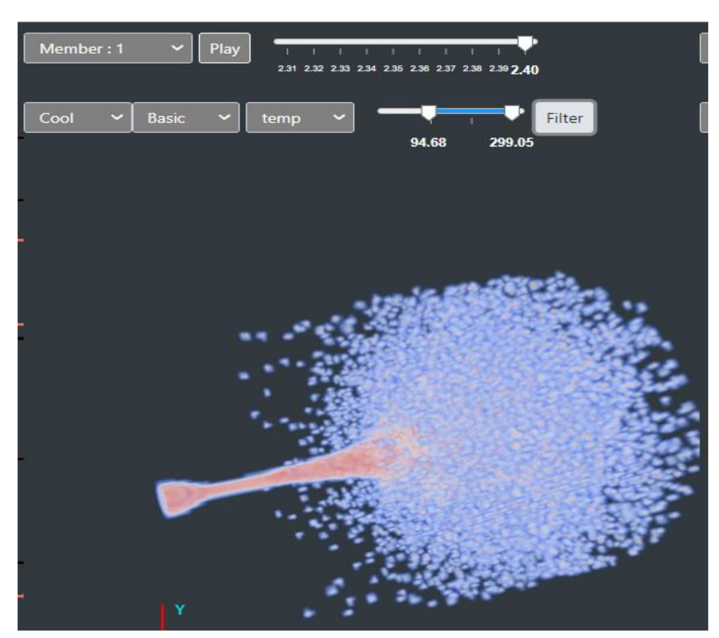

Fig 3: Volumetric 3D view showing particles at a specific time step (2.40s) of a single ensemble member, filtered by temperature

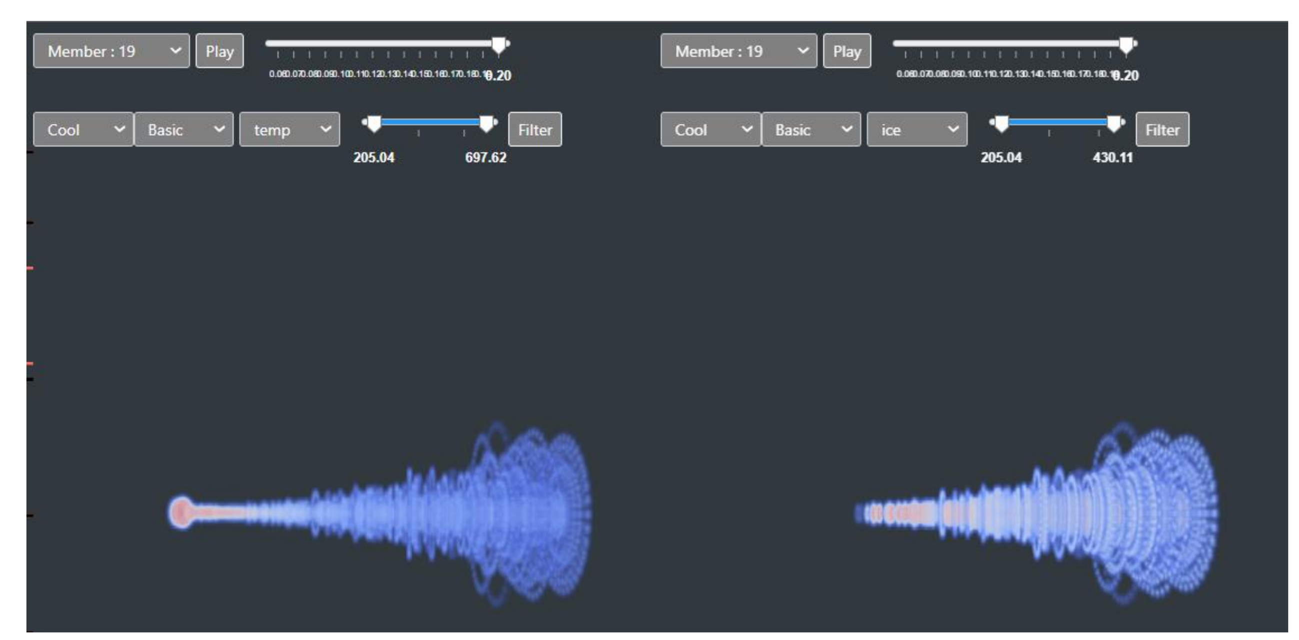

Fig 4: Two volumetric 3D views showing particles of ensemble member 19 at 0.2s, colored by temperature. The left view shows all particles, and the right view shows only ice particles. It is clear that ice starts to form as the particles get further from aircraft engine

Fig 5: Ensemble Member Similarities View, showing 2D projection of all ensemble members using Principal Component Analysis (left). A query panel on the right can be used to cluster similar members based on user-selected parameters

EVALUATION

- We conducted a qualitative evaluation with two domain experts.
- The use of multiple linked views yielded positive feedback.
- Filtering ensemble members based on their input and output parameters was considered very helpful to assess their similarities.
- The PCA projection assisted the domain expert with understanding the similarities between ensemble members and identifying outliers.
- The animation feature confirmed the domain expert's intuition about contrail formation and evolution.

CONCLUSION

Our multi-scale interactive visual analysis helped domain expert to explore trends and anomalies within the data, as well as to detect and analyze formation and evolution of contrails.

Future work will include comparison between ensemble members, manipulation of input and output parameters to find ways to minimize the formation of the contrails, and way to support automatic detection and tracking of contrail-related spatial features.

ACKNOWLEDGEMENTS

This work is supported by awards NSF-IIS-2031095, NSF-CDSE-1854815 and NSF-CNS-1828265.

REFERENCES

1. C. Floricel, N. Nipu, M. Biggs, A. Wentzel, G. Canahuate, L. Van Dijk, A. Mohamed, C. D. Fuller, and G. E. Marai. Thalis: Human-machine analysis of longitudinal symptoms in cancer therapy. IEEE Trans. on Vis. and Comp. Graph., 2021.