Investigating effective approaches for predicting spray flame location and NO_X emissions

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Abstract

An analysis was done to investigate different approaches for predicting spray flame location and NOx emissions using a Parker UEET injector consisting of a Macrolaminated air swirler with an integrated pressure swirl atomizer[1]. The air and fuel from the swirl cup discharged into a 3×3×12 in^3 confining chamber .Three dimensional simulations were conducted of both non-reacting and reacting flows using Fluent. The full three-dimensional flow of air through the swirler and the downstream domain was modeled. At first, a non-reacting case was run using a fixed pressure drop for the air. A reacting case was then run using fixed airflow rate. For the non-reacting conditions, a constant pressure drop of 4000 Pa was applied across the swirler, with the exit pressure equal to 1 bar. (i.e., 4% pressure drop). A flamelet model was used as a combustion model and $C_{12}H_{23}$ was used as a surrogate for Jet-A fuel. An unsteady flamelet model was used in a post-processing step to estimate NO emissions. The Parker UEET injector proved highly successful in high-pressure combustion tests where record low emissions were obtained[2].

CFD Model

•Structured multi-block grid system was generated using the **GridPro**

• The grid system contained a little over **$2.0 \cdot 10^6$ hexahedral cells**

•The effects of turbulence on flow were modeled using realizable **k –epsilon turbulence model**.

•Combustion model: **31 step reaction mechanism** with **21 species** was used in the Flamelet combustion model.

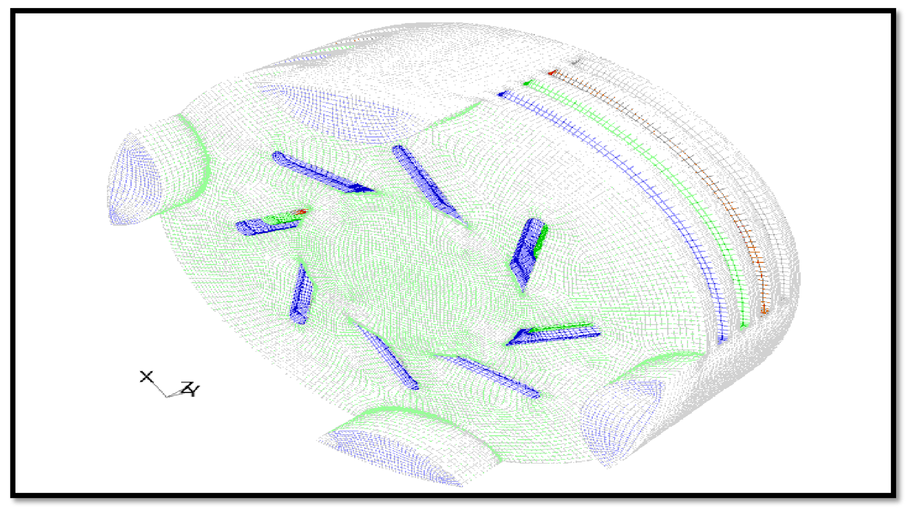

Fig1 :A multi-block grid system for the air passages within the ML swirler

Problem Description

•The air swirler was designed for target swirl number of 0.8.

•The swirler was constructed from a stack of metal plates with air swirl passages etched into each plate that fed a 0.43" diameter "spray cup" that was 0.30" deep.

•The pressure swirl atomizer injected fuel at the bottom of the spray cup exposing the spray directly to the incoming swirling air.

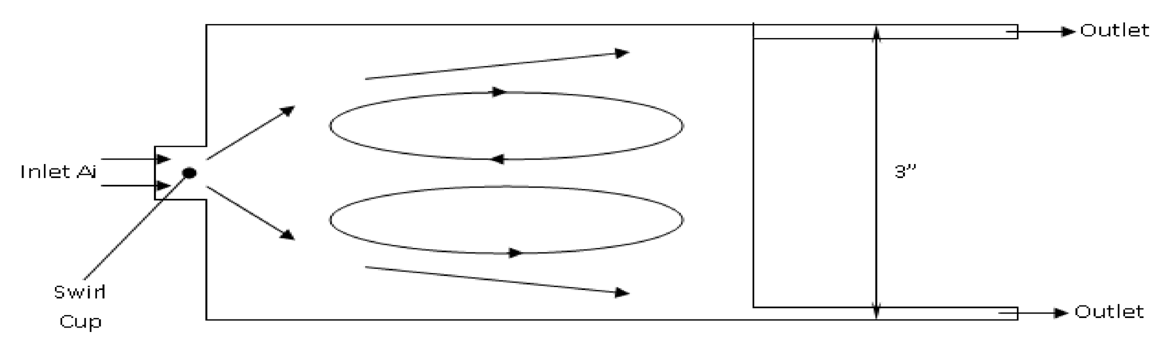

Fig 2: Schematic of flow domain used in CFD

Spray Model

Model:	Discrete Phase Model
Particle Type :	Droplet
Particle distribution:	Rosin-Ramler Distribution
Injector:	Hollow Conical Spray
Spray angle:	80^0
Sauter-Mean Diameter:	20 µm
Spread Parameter:	1.8

Results

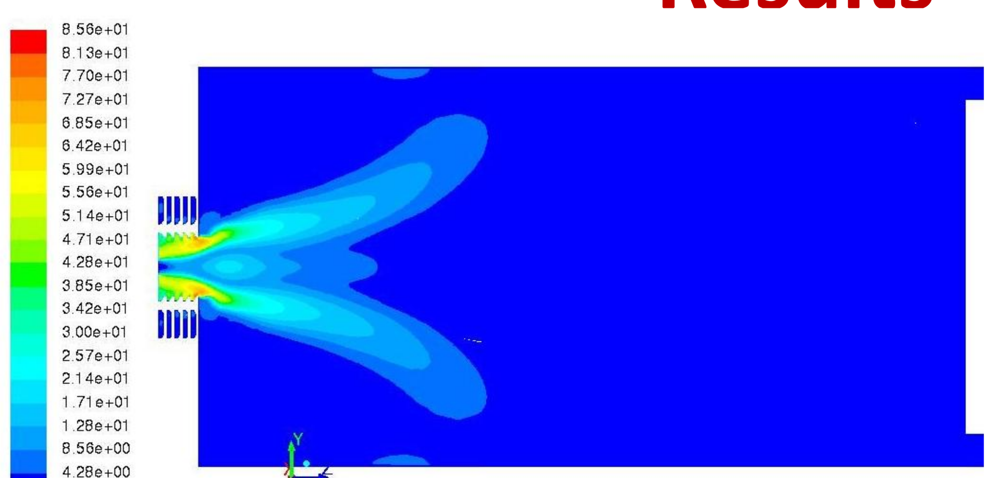

Fig3: Non-reacting velocity field

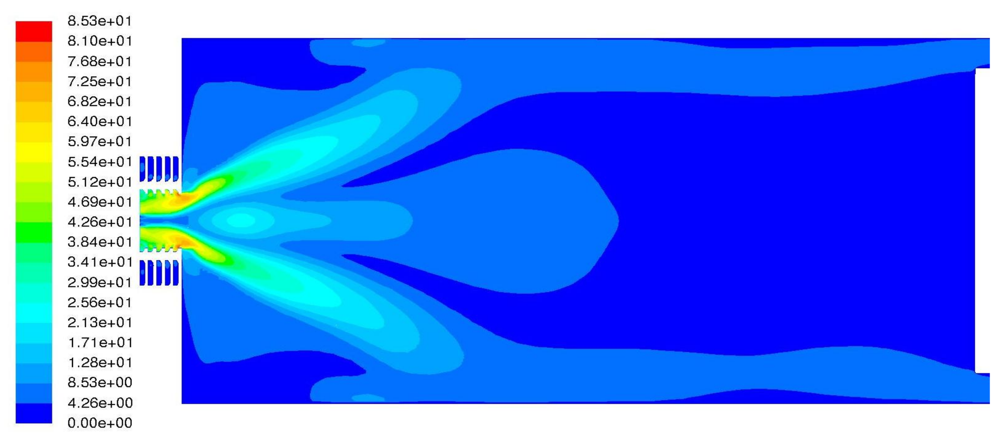

Fig4: Reacting velocity field

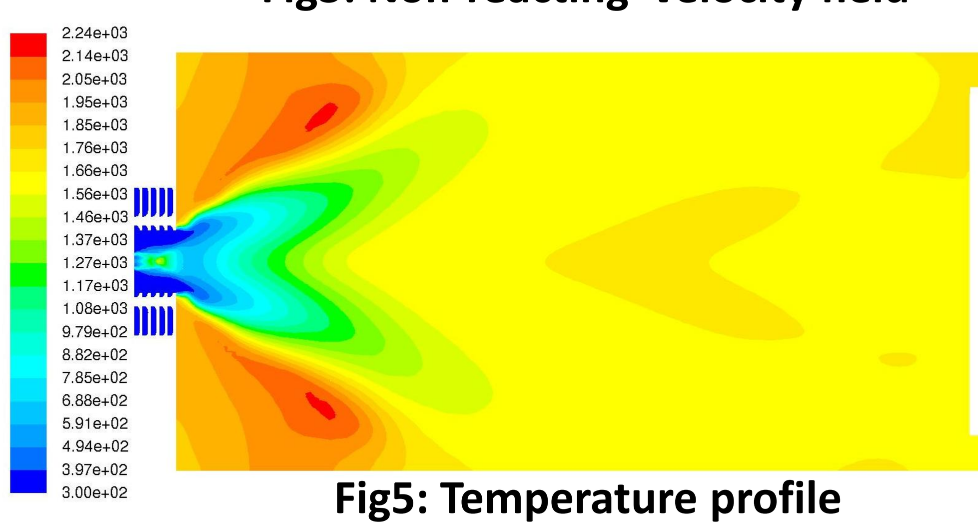

Fig5: Temperature profile

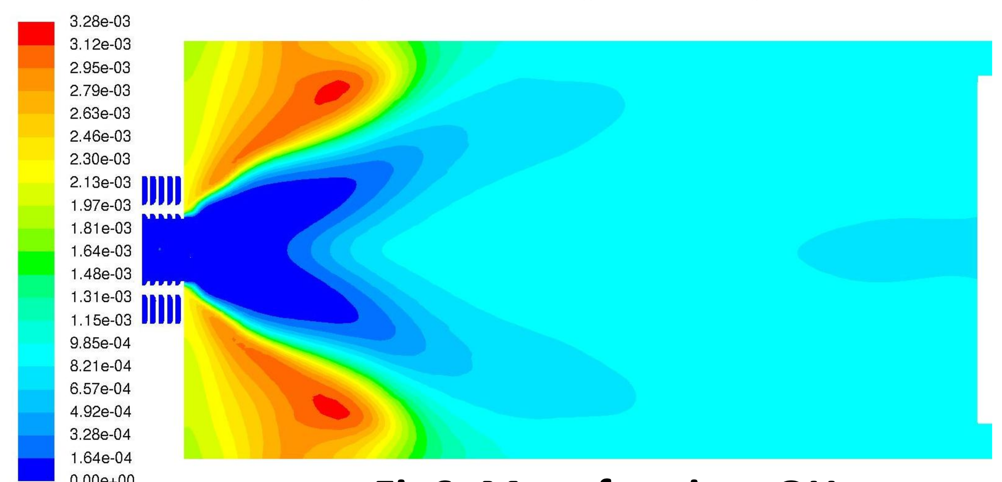

Fig6: Mass fraction OH

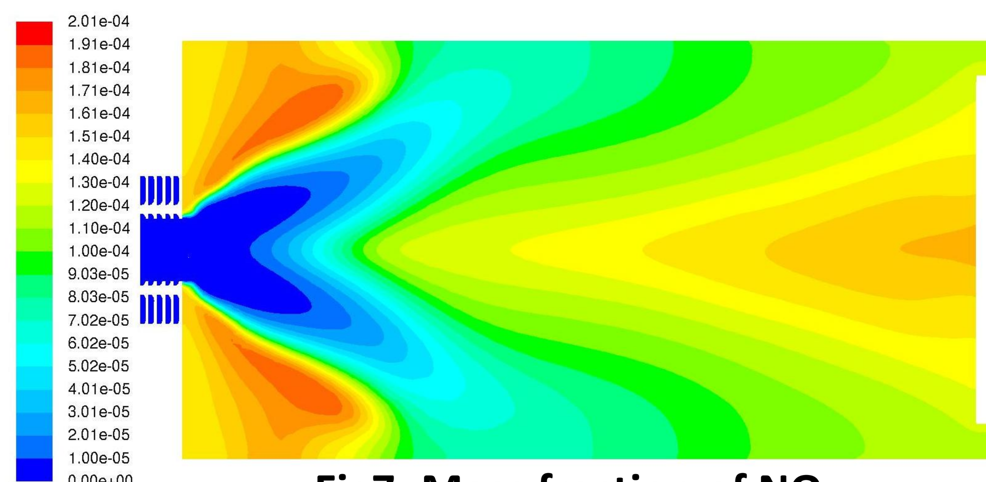

Fig7: Mass fraction of NO

Summary

•Strongly swirling flow downstream of the exit and swirl induced vortex breakdown stabilized the flame.

•Temperature profiles for the reacting flow shows **the maximum temperature is 2240 K and exit temperature is 1638 K** with the burning zone positioned downstream of the cup.

•An unsteady flamelet model was used as a post processing step to estimate NO emissions

•NOx produced in high temperature regions and where residence time for fluid particles were long (consequence of flame tube setup).

• NOx emissions were predicted to **be 3.7 g-NO/kg-fuel**

References

[1] Cai, J., Jeng, S.-M., Steinthorsson,E., "Experimental and Numerical Investigation of a Macro-Laminated Radial Swirler", AIAA 2003-0826.

[2] Tacina,R.,Wey,C.,Laing,P.,Mansour,A., "Sector test of a low NOx, lean-direct-injection, multipoint integrated module combustor concept,"ASME Turbo Expo2002.