Numerical Investigation of Multi-Phase Trapped Vortex Combustor and Afterburner with Pulse Injection Using Jet-A Fuel.

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ABSTRACT

This paper describes the development and surveys liquid fuel spray droplet modeling methods as used in the simulation of Trapped Vortex Cavity (TVC) combustors and afterburners. TVC's have demonstrated exceptional engineering performance characteristics in tests, including high combustion efficiency, low pollutant emissions, and lean blowout performance. The combustion zones in the TVC are staged radially, instead of axially, offering a compact design that may provide some advantages over conventional rich-quench-lean combustor designs. Configurations investigated include a single cavity with two driving air injectors afterburner TVC designs, with mixing augmentation provided by differential diffusion. While good agreement between experiment and simulation have been achieved in terms of predicting flow structures and combustor exit temperature, much remains to be understood in the details of the TVC's operation. Additional understanding of the details of the vortex residence times, entrainment of the cavity flow into the free stream, and pumping effects for inboard and outboard cavities in the presence of swirl are required. To extract this level of operational performance detail, the underlying accuracy of the simulation models must be well understood. In the case of CFD modeling of the TVC, primary attention is drawn to the liquid fuel spray droplet modeling, particularly the assumptions used on specifying spray initial conditions, such as droplet size distribution, velocity magnitude and directions, temperature, and injection location.

The results of detailed three-dimensional, reacting, computational fluid dynamics (CFD) simulations of several afterburners are presented. The results from these simulations are used to facilitate the design of augmentor system technologies that have the potential of reducing emissions without sacrificing performance. The simulations are used to evaluate different fuel location and air injection configurations to identify and mitigate potential high temperature regions and to improve mixing. Furthermore, these simulations are useful for identifying key variables to investigate experimentally.

Finally, this paper is also collates the literature and summarizes current state-of-the-art in specifying spray droplet boundary conditions with regard to TVC performance predictions. The paper will draw on the authors' direct experience, and other work related to these devices. An attempt will be made to identify best practices and to provide guidance for improvements in this area of CFD modeling. This work represents a preliminary analysis leading to future efforts on Jet –A pulse injection in TVC.

Introduction

The trapped vortex combustor (TVC) is a fundamentally different approach to stabilize a flame. In conventional flame stabilization approaches, swirl, bluff-body, and rearward facing steps are used to create low velocity re-circulation zones into which hot products are entrained to stabilize the reaction. In these conventional approaches, the location, strength, and stability (temporal and/or spatial) of the re-circulation zones are coupled to the main flow in the combustor. In the trapped vortex combustor, the flame is stabilized by a vortex that is virtually independent of the main stream. Flame stabilization recirculation zones are established by air swirling around the fuel injectors as shown in Figure 1. This recirculation zone transports some of the hot combustion products back toward the combustor face and ignites the incoming fuel and air as it is mixed in the combustion chamber. Strategically placed air and fuel injection points in the forward and aft walls of the cavity drives the vortex inside the cavities. The created vortex recirculates the hot combustion gases within the cavity, and then the gases are exhausted out of the cavity and transported along the face of the combustor.

The trapped vortex combustor offers several advantages over more conventional combustor designs. Relative to bluff-body and rearward facing steps, the trapped vortex approach is stable over a much wider operating range (,Refs.1-7) Relative to swirl-stabilizer combustors, the main recirculation zone is shielded from minor flow upsets that may extinguish weakly stabilized swirl flames. Therefore, the trapped vortex combustor provides flame stabilization over a wide range of overall fuel-air mixtures, a simple and compact flame, heat release rate, operability, weight, and even a lower cost, and may offer the potential for achieving lower levels of pollutants, such as NOx.

To achieve a more efficient engine, the next generation burner and augmentor designs must address the following requirements: 1) more severe inlet temperatures, 2) more flexibility in the choice of fuels, particularly in light of the recent volatility in fuel prices, and 3) more stringent pollutant regulations. This paper describes the development of augmentors that addresses the issues listed above. This paper describes the trapped vortex combustor concept for an augmentor and its application. Several three-dimensional, reacting, simulations using a state-of-the-art CFD code are used to investigate different geometric configurations and operating conditions. In addition to helping guide the prototype hardware design, these modeling activities have identified some important experimental variables to investigate in a future test program at General Electric (GE).

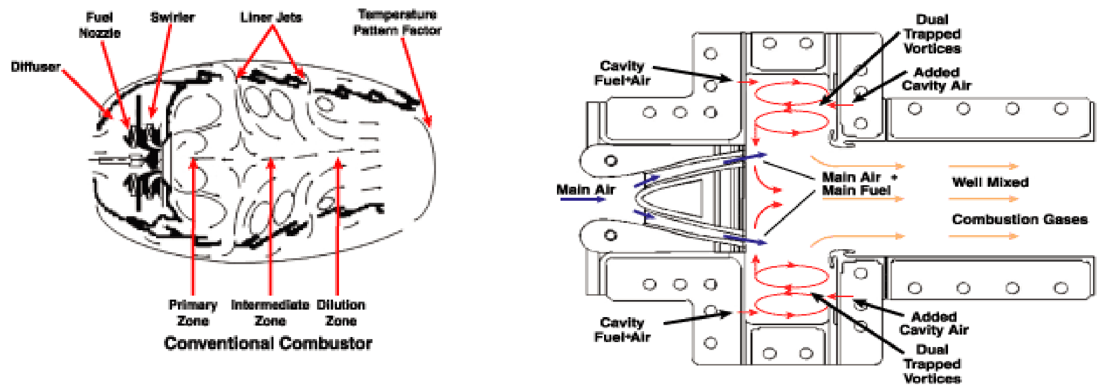

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Figure 1: a) Conventional Combustor. b) TVC Cross Section

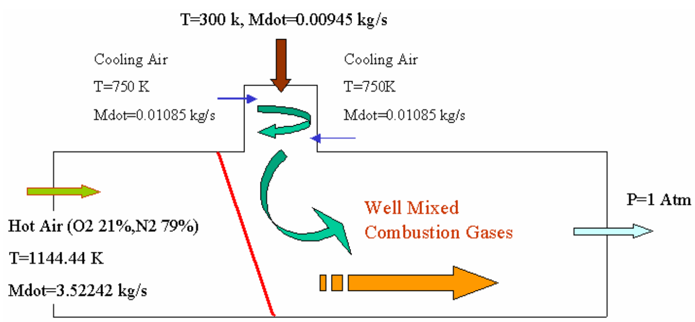

Figure 2: TVC Afterburner and Flow Operating Conditions

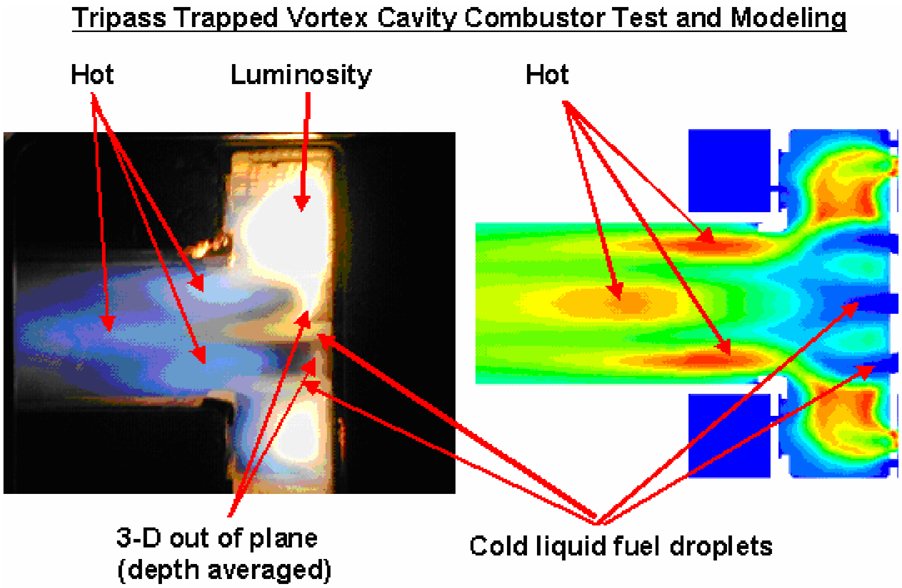

Figure 3: Flow visualization of a linear array TVC with tri-pass diffuser. CFD simulation of the static temperature agrees well with the experimental flame luminosity.