Geometry and Boundary Specifications of the MiGaDome Facility for the First Annual ASTFE Nuclear Thermal Hydraulics CFD Competition

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1. INTRODUCTION

The first annual nuclear thermal-hydraulics Computational Fluid Dynamics (CFD) competition organized by the American Society of Thermal and Fluids Engineers (ASTFE) will be held at the 9th Thermal and Fluids Engineering Conference. The University of Michigan's multi-jet Gas-mixture Dome (MiGaDome) facility has been selected to provide benchmark experiments. Blind data will be collected from the MiGaDome facility and used for accessing the CFD simulations conducted by the participants. This document provides an overview of the experimental facility and includes the necessary boundary conditions and the data collection locations that all participants will use.

2. DESCRIPTION OF THE MIGADOME FACILITY

The MiGaDome facility was designed and built in the Experimental and Computational Multiphase Flow Laboratory (ECMFL) at the University of Michigan. The purpose of the facility is to study mixing in large enclosures widely seen in nuclear reactor designs and to provide high-resolution experimental data for code validation and development [1–3]. Figure 1 shows the dimensions and schematics of the test section. The main test section consists of a large enclosure with a dome-shaped surface. Six inlets connected to long straight pipes are located on the bottom plate in a hexagonal pattern, and twelve small outlets are distributed evenly in the periphery region of this enclosure's bottom plate. Each inlet branch is individually controlled with the flexibility to inject different gases or gas mixtures. The gas is supplied either by gas cylinders (helium, argon, air) or by the building's compressed air supply. During the experiment, the gas passes through the long inlet straight pipe, discharges into the dome, and mixes within the enclosure. The mixed flow then leaves through the small periphery outlets into the atmosphere. More description of the experimental facility can be found in Ref. [4].

Figure 2 shows the main measurement technique used for data acquisition. The flow field in the test section is captured using a 2D Particle Image Velocimetry (PIV) system. The PIV measurements can obtain high-resolution two-dimensional velocity and turbulent statistics fields. Laser Dopper Velocimetry (LDV) is also utilized to monitor velocity profiles at the inlet boundary, which provides accurately defined boundary

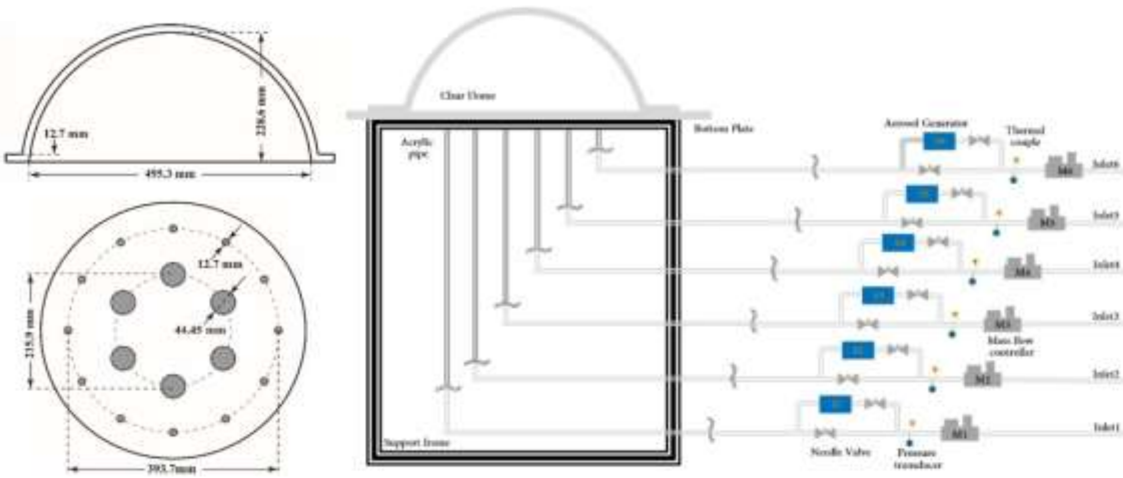


Figure 1. Dimensions and schematics of the MiGaDome facility.

conditions. First- and second-order statistics are available for code validation. Figure 3 shows an example of the instantaneous flow field, mean vector field, and a comparison with CFD from one of the uniform-density cases [5]. Some experimental data have been used to validate the state-of-the-art GPU-oriented CFD code NekRs with excellent agreements [6, 7].

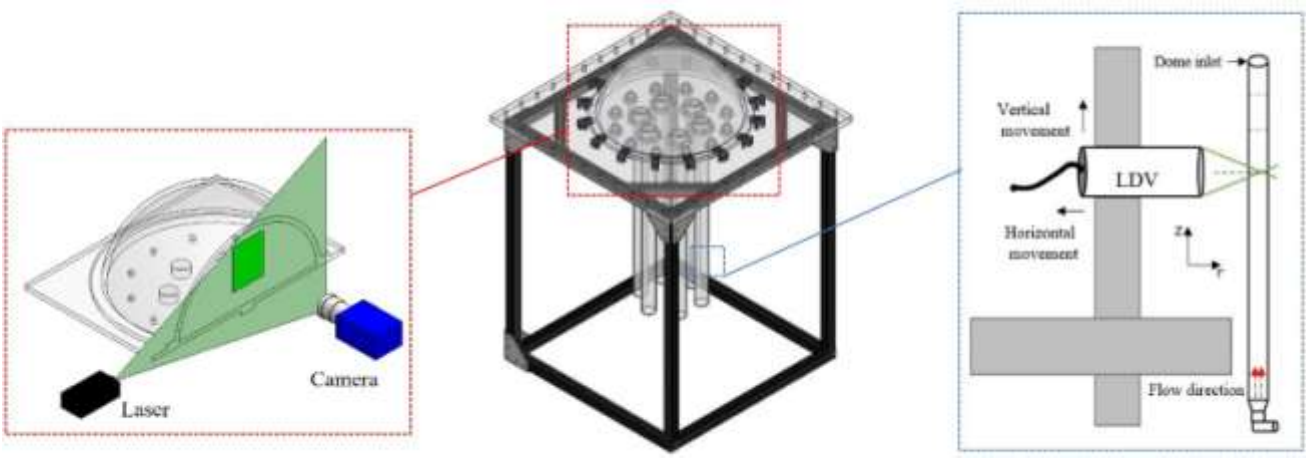


Figure 2. Measurement technique for the MiGaDome facility.

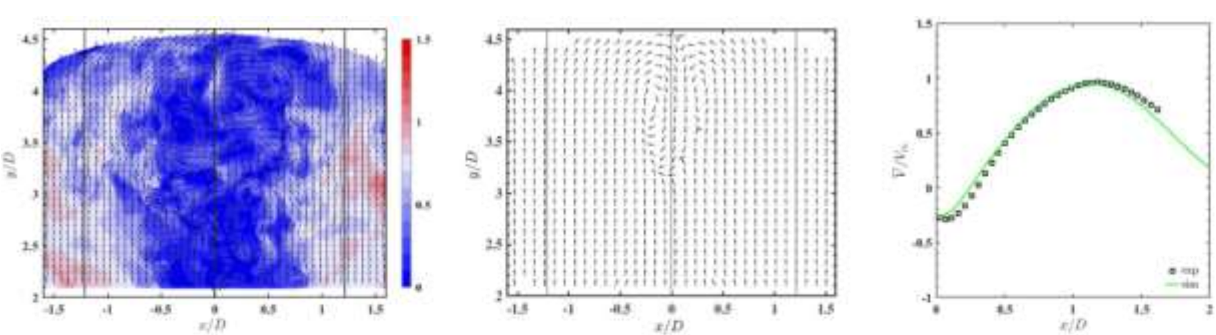


Figure 3. Data example from one of the uniform-density cases.

3. SPECIFICATION OF THE COMPETITION BENCHMARK EXPERIMENT

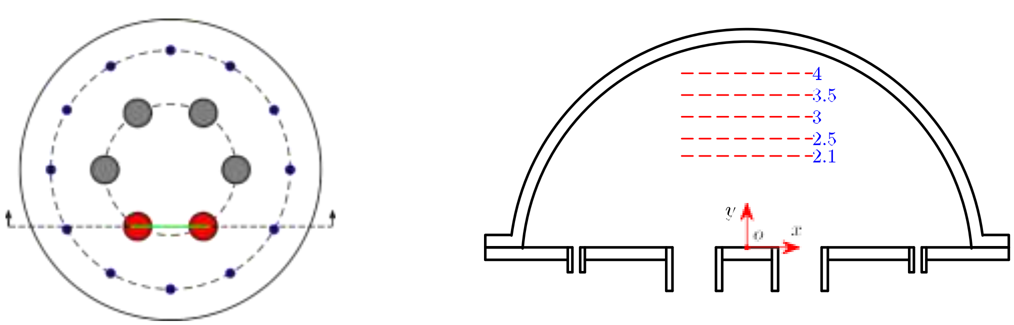
The benchmark experiment for this competition is a two-jet case with argon and air as the working fluids. The fluid properties and the boundary conditions are summarized in Table I. The Reynolds number is based on the inlet jet diameter $D = 44.45\ mm$ and the gas density at ambient pressure. Based on the LDV measurement, a fully developed velocity profile has been reached for both Reynolds numbers before entering the dome [4].

Table I. Fluid properties and boundary conditions

Gas	Argon	Air
Mass flow rate $\dot{m}$ ($\times 10^{-3}$ kg/s)	3.19	2.60
Density ρ (kg/m3)	1.63	1.20
Viscosity μ ($\times 10^{-5}$ Pa · s)	2.28	1.82
Reynolds number Re	4070	4100

Figure 4 shows the injection scheme and the measurement plane. The experiment was conducted in the following manner: The dome was initially filled with ambient air. Argon and air were discharged into the enclosure with controlled mass flow rates through two neighboring inlet shown in Figure 4a (in red color), while the other four inlets (in gray color) remain at zero flow rate. All the outlets are open to the ambient during the experiment. Note that the left inlet was connected to argon, and the right inlet was connected to air. The mixing process in the dome was measured through the PIV system with an acquisition frequency of 15Hz. The low frequency helped guarantee data independency between PIV image pairs. Two runs were repeated, with each run taking around 3000 image pairs. The repeatability of the experiments has been well-confirmed by comparing statistics from the two runs.

The 2D measurement plane is located at the region that crosses the two jet inlets (green line). Figure 4b shows the front view of the measured plane. The origin of the coordinate system is set to be at the center between the two inlets. x, y, z refer to the lateral, streamwise, and spanwise (i.e., out-of-plane) directions. The corresponding mean velocity components and velocity fluctuation components are denoted as $\overline{U}, \overline{V}, \overline{W}$ and u', v', w'. The profiles of the first- and second-order statistics, namely the streamwise velocity, the Reynolds normal stresses, and the Reynolds shear stresses, at $y/D = 2.1, 2.5, 3.0, 3.5,$ and 4.0 should be extracted from the CFD simulations by the participants to compare with the experiments. Note that no w' information is available. The participants are also encouraged to include other quantities for potential future data analysis purposes.



(a) Top view. **(b) Front view.**

Figure 4. Views of the measurement plane.

4. WINNER DETERMINATION

Data matching assessment will be carried out in two stages. First, each team's CFD curves of streamwise velocity, Reynolds normal stresses, and Reynolds shear stresses, at $y/D = 2.1, 2.5, 3.0, 3.5,$ and 4.0 (20 curves total) will be compared directly to their experimental counterparts. The "fitness" metric for each of the 20 pairs of curves will be found using the traditional $R =$ coefficient of determination approach. A "total fitness" will be computed as the sum of the 20 individual "fitness" values. Finally, the "total fitness" will be divided by each competitor's CPU and/or GPU kWhconsumption to the one-half power to produce an "effective fitness". In other words, groups having/utilizing access to massive HPC facilities will be penalized more than others. The idea is that a more sustainable future is sought as we find solutions using fewer resources. When computing the CPU/GPU usage, **nameplate** kW values should be utilized for the cores, and total wall-time should be considered for the duration.

A sample effective fitness calculation is shown on the right. The five y/D locations and their associated streamwise velocity, Reynolds normal stresses, and Reynolds shear stresses are arranged vertically. The far-right column includes arbitrary R fitness values from curve comparisons (not shown). The sum of those is 16.1, and the sum of the CPU and/or GPU energy consumption is 2900 kWh. Finally, the effective fitness value that will determine the team's score $= 16.1/2900^{0.5} = \mathbf{0.30.}$

Location	Quantity	R
2.1		0.93
2.5		0.67
3.0	V	0.79
3.5		0.61
4.0		0.99
2.1		0.83
2.5		0.96
3.0	<u'u'>	0.71
3.5		0.89
4.0		0.83
2.1		0.94
2.5		0.90
3.0	<v'v'>	0.81
3.5		0.84
4.0		0.60
2.1		0.81
2.5		0.61
3.0	<u'v'>	0.72
3.5		0.76
4.0		0.85

Total Fitness	**16.1**
kWh	**2900**
Effective Fitness	**0.30**

5. RESULTS SUBMISSION DUE DATE

CFD results in .csv format should be submitted to Wayne Strasser by April 1st 2024. All comparisons between competitors and the experiments will be provided at an in-person session at the conference. Competitors must be physical present to win. (This is our current policy, but it may change.)

6. ACCESS TO CAD GEOMETRY

The CAD geometry for the test section has been created and can be accessed by interested participants through this link.

7. ADDITIONAL CONTACT INFORMATION

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