*Appendix B*

# CONSIDERATIONS FOR FLOW DEVELOPMENT OF A MODULE WITH NON-NEGLIGIBLE INLET GEOMETRY

The FAWT in the Aerodrome within CAST at Caltech, unlike any of the other builds mentioned throughout this dissertation, uses a series of modules with inlet geometry to build up a bigger array. The open air wind tunnel is comprised of a $12 \times 12$ grid of slightly diverging ducts that feed air to a $3 \times 3$ fan distribution per duct, totaling $36 \times 36$ total fan units. When viewed from a perspective downstream of the array looking back, the array appears as any other FAWT, however, flow visualizations show that the influence of each $3 \times 3$ module is noticeable an appreciable distance downstream. The flow evolution of an isolated module sheds some light on the funneling influence and subsequent core convergence associated with the divergent inlet geometry, shown in fig. B.1. Immediately downstream of the outlet, spanwise (z-y plane) visualization of the module shows the annular flow output of the nine total fans, just as in the $3 \times 3$ array presented in fig. 2.4. Differences in the flow evolution emerge for a constant commanded RPM fan distribution, however, with increasing distance downstream compared to builds without the module inlet geometry on account of the difference in boundary conditions at the fan intake. Namely, the useable uniform core region converges much more quickly than in fig. 2.4. The area of the core region of the flow for both builds is $\sim L \times L$ at $x/L = 0.5$. Beyond $x/L > 0.5$ (where the effect of each individual has mixed into a bulk flow), the core area reduces from a square cross section to a circular cross section as fluid is entrained. At $x/L = 4.23$ the $3 \times 3$ module has a cross sectional area of approximately $0.45 \cdot (L \times L)$ compared to the build without inlet geometry that has a cross sectional area of approximately $0.75 \cdot (L \times L)$ at the same downstream location at comparable flow speeds. The core convergence of a single module is made more readily apparent when velocities below a certain threshold are subtracted away, as in the visualization of fig. B.2.

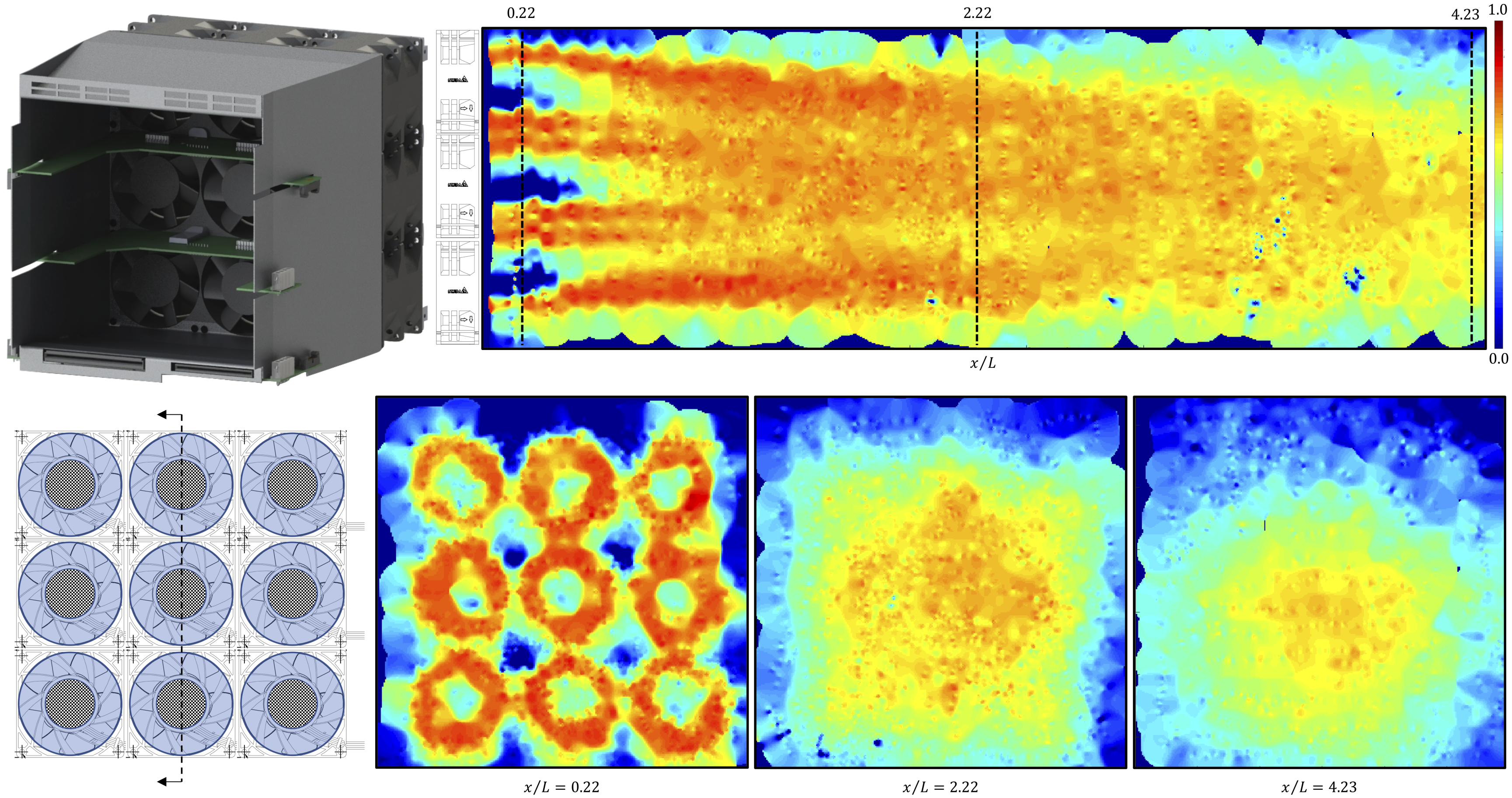


Figure B.1: Development of a steady uniform flow measured for a $d/L = 0.33$ resolution array ($d = 0.080$ m) with a diverging duct mounting structure at fan unit intake. The streamwise (x-z plane) cut corresponds to the centerline ($y = 0$) and the positions of the spanwise (z-y plane) distributions are dashed for all three locations. The core flow homogenizes first from discrete source units to a nearly uniform square cross section of size $\sim L \times L$ and then spatially reduces with downstream distance as the core flow smoothes to a rounder cross-section as the boundary shear layers entrain and grow. The colorbar corresponds to $\overline{u}/\overline{u}_{max}$.

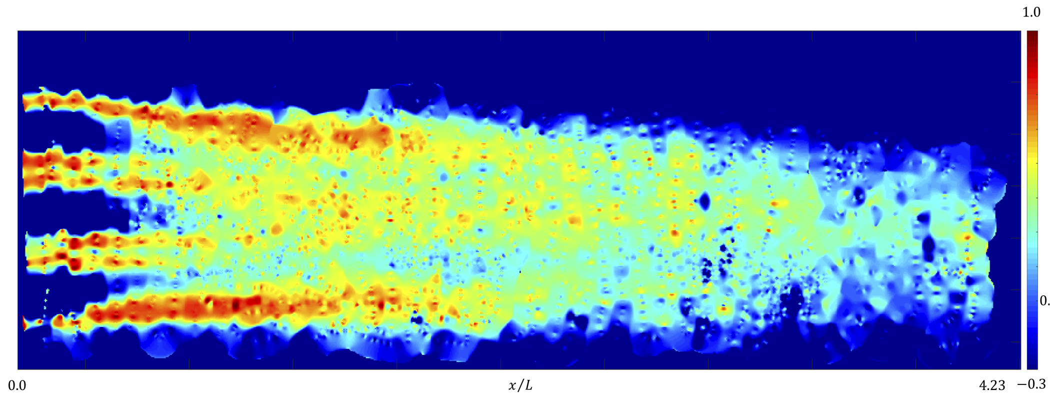


Figure B.2: Streamwise (x-z plane) visualization of a $d/L = 0.33$ resolution array ($d = 0.080$ m) with a diverging duct highlighting the core convergence of a single $3 \times 3$ module for a commanded constant RPM input condition. The colorbar corresponds to $\Delta\overline{u}_T/\overline{u}_{max}$, where $\Delta\overline{u}_T$ is the difference between the mean velocity $\overline{u}$ and a certain threshold value $\overline{u}_T$.

With a diverging duct geometry installed upstream, each of the eight fan units encircling the center fan unit of a given module have at least one boundary condition adjacent to a solid surface. The corner fan units each have two boundaries along a surface whereas the center fan intakes free from any surface. These differences in boundary conditions create a funneling preference to the center fan that steepens the velocity profile away from a rounded flat top to that resembling more of a parabolic shape. When modules with parabolic-like velocity profiles are installed adjacent to one another, a peak-and-valley distribution remains for a greater distance downstream, as seen in fig. B.3.

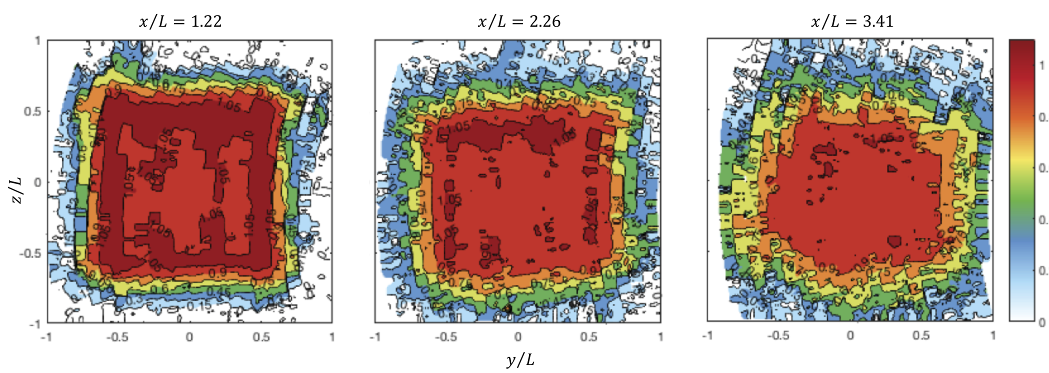


Figure B.3: Spanwise (z-y plane) visualization of a $d/L = 0.11$ resolution array ($d = 0.080$ m) comprised of nine total ($3 \times 3$) modules assembled into a $9 \times 9$ array. The colorbar corresponds to $\overline{u}/\overline{u}_{0,0}$, where $\overline{u}_{0,0}$ is the center velocity at $z/L = y/L = 0$.