1 Numerical Approach

1.1 Solver

2 Uncertainty Analysis

2.1 Numerical Uncertainty

The Grid Convergence Index (GCI) method was used to quantify numerical uncertainty. Four comparison metrics were computed for each of the five downstream locations. The metrics were: centerline velocity, centerline TKE, integrated velocity and integrated TKE. For each of th metrics

$$\begin{aligned} p^{n+1} &= \frac{\ln|\frac{f_3-f_2}{f_2-f_1}| + q(p^n)}{\ln r_{12}} \\ q(p) &= \ln\frac{r_{12}^p - s}{r_{23}^p - s} \\ s &= \operatorname{sign}\left(\frac{f_3-f_2}{f_2-f_1}\right) \\ r_{12} = \sqrt[3]{\frac{N_2}{N_1}},\ r_{23} &= \sqrt[3]{\frac{N_3}{N_2}},\ N_1 > N_2 > N_3 \end{aligned} \tag{1}$$

was iterated until

$$\frac{p^{n+1}-p^n}{p^n} < 1\times 10^{-9} \tag{2}$$

to find the observed order of convergence, p. The numerical uncertainty is then

$$u_{\text{num}} = \frac{F_s}{r_{12}^p - 1}|f_1 - f_2| \tag{3}$$

where

$$F_s = \begin{cases} 1.25 & \frac{p-2}{2} < .1 \\ 3 & \text{otherwise} \end{cases}. \tag{4}$$

Any metric that produced erroneous results such as oscillatory convergence, negative observed convergence, observed convergence greater than 10, or negative uncertainty were thrown out. The max relative uncertainty generated from the surviving metrics was chosen as the relative uncertainty for the entire velocity, TKE, and concentration profiles.

Case N337 was run with 180 000, 135 000, and 90 000 volumes. Table 1 shows the metric used and the resulting observed order of convergence and relative uncertainty at each of the five downstream locations. Centerline k was used for all five locations. The velocity, TKE and concentration profiles are provided in Appendix A.

2.2 Input Uncertainty

2.3 Model Uncertainty

TABLE 1
The metric used and resulting observed convergence and relative uncertainty at each of the five downstream locations.

Distance (mm)	Metric Used	Observed Convergence	Relative Uncertainty
050	k	2.28	0.292
150	k	1.87	0.0773
250	k	3.35	0.0573
350	k	3.49	0.0386
450	k	2.5	0.0423

A Profiles

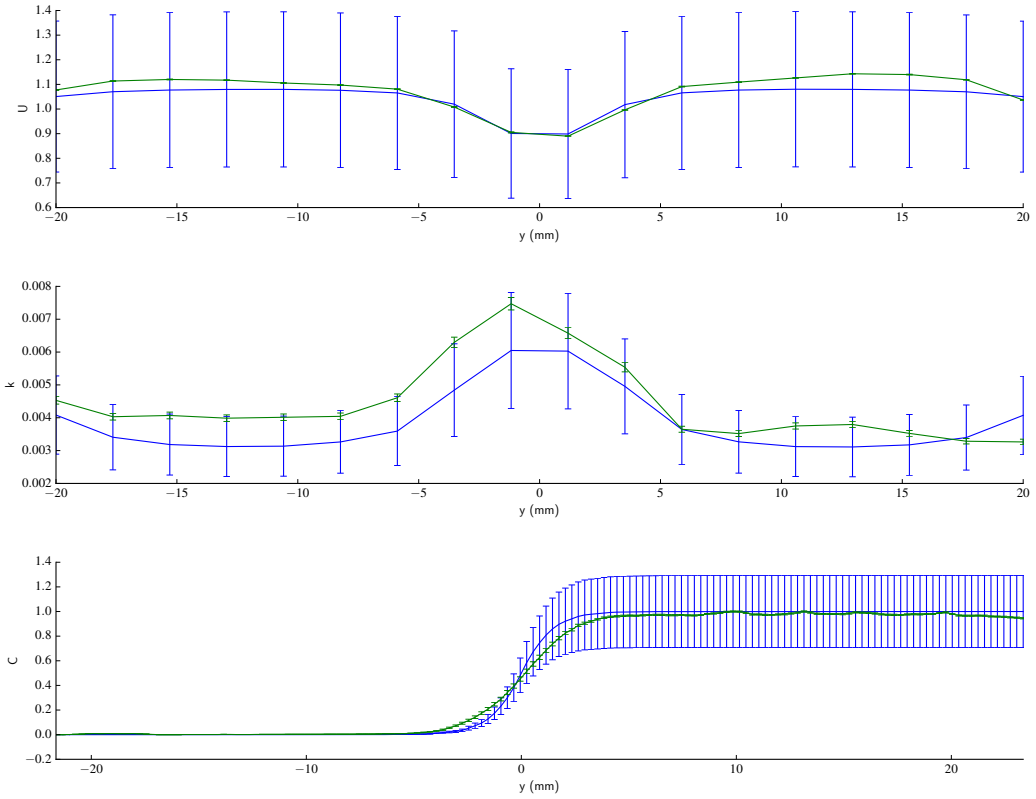

Fig. 1. The velocity, turbulent kinetic energy and concentration profiles at 50 mm downstream.

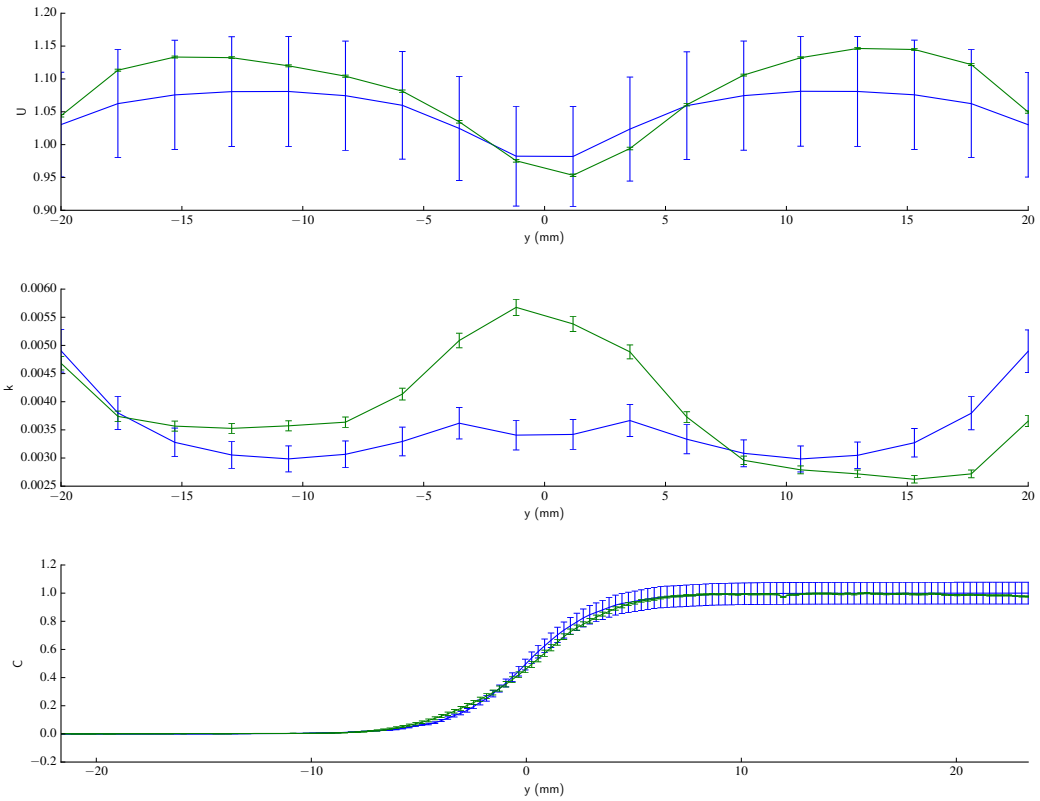

Fig. 2. The velocity, turbulent kinetic energy and concentration profiles at 150 mm downstream.

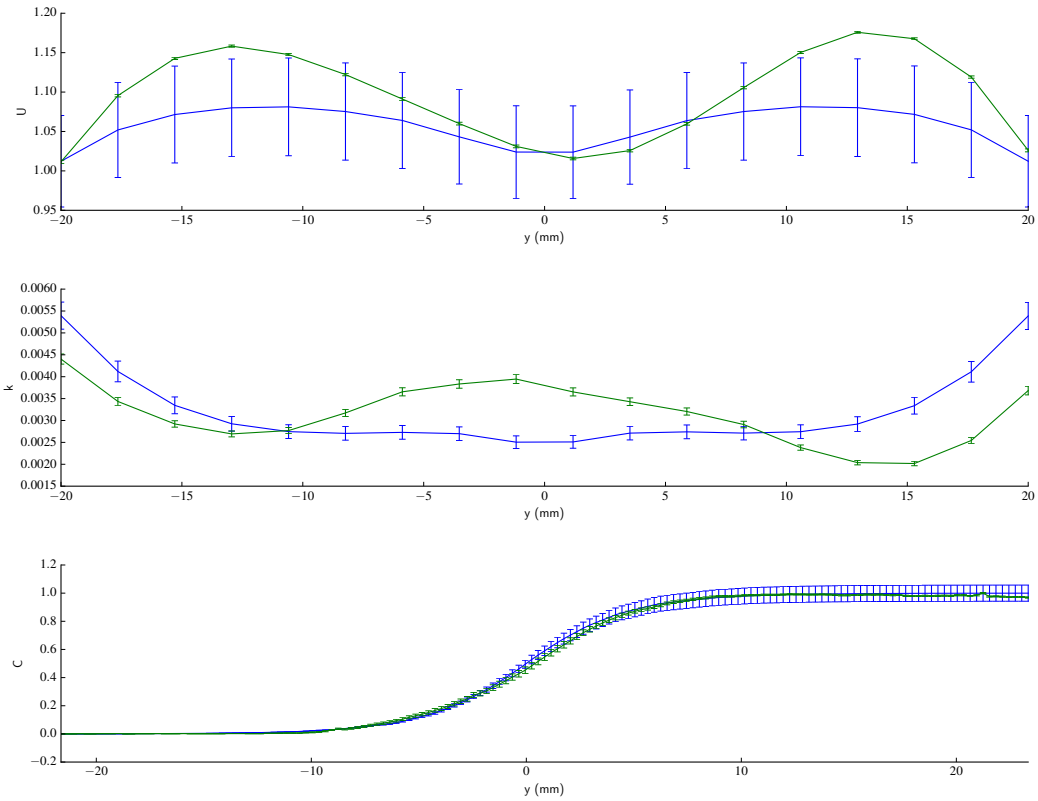

Fig. 3. The velocity, turbulent kinetic energy and concentration profiles at 250 mm downstream.

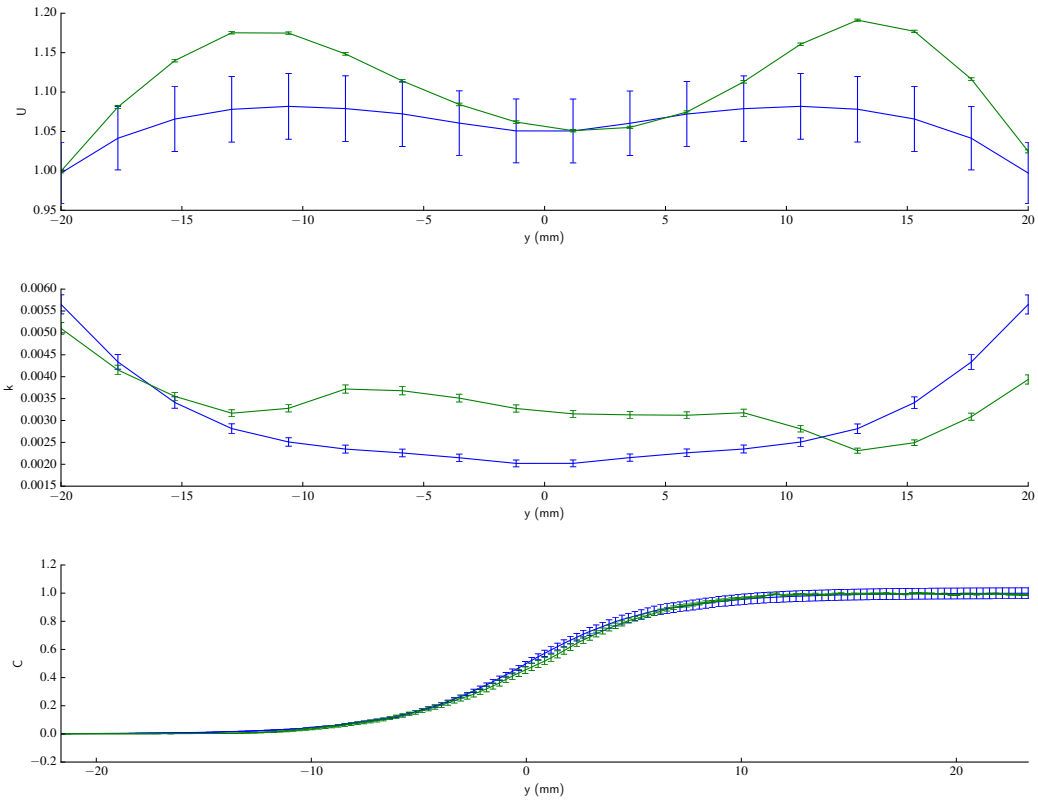

Fig. 4. The velocity, turbulent kinetic energy and concentration profiles at 350 mm downstream.

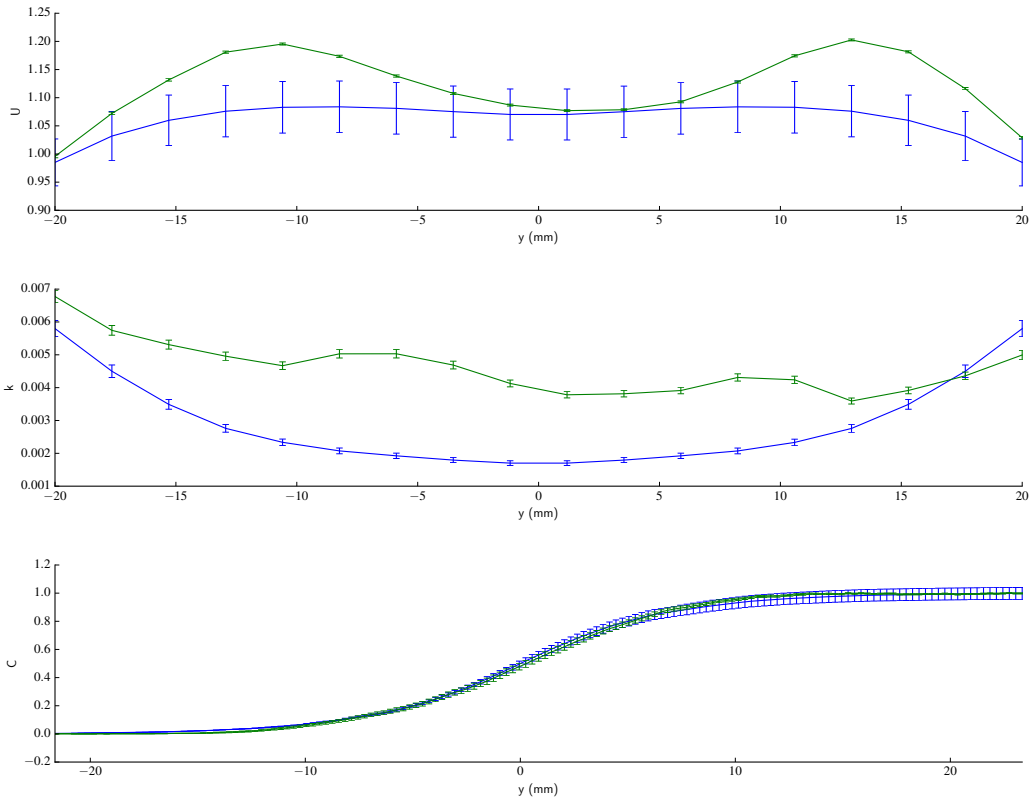

Fig. 5. The velocity, turbulent kinetic energy and concentration profiles at 450 mm downstream.