Computational Fluid Dynamics or Wind Tunnel Modeling?

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CFD holds great promise for replacing the wind tunnel in coming years as the science behind CFD improves and computers become more powerful. Currently, CFD can provide results almost as accurate as a wind tunnel that are often more useful due to the sophisticated visualization and domain wide measurements characteristic of CFD. For building services, CFD is an effective tool for simulating wind climate to analyze pedestrian comfort, and pollution dispersion. It can also be used to assist engineers with natural ventilation design and building wind loading.

I. Current Status

- Wind Tunnel modeling is generally accepted in the scientific and engineering community. Wind tunnel results have been proven to be representative of real world situations when the modeling correctly accounts for the features of the atmosphere and scaling is exact.
- Computational Fluid Dynamics (CFD) is a well-proven tool that was economically feasible only on mainframe computers until recent advances in computing made it possible to use a desktop PC. However, CFD results may not be as comprehensively comparable to real world results as most wind tunnel results can be.
- Many CFD validation studies have shown quite comparable results to real world or wind tunnel studies.
- Many CFD results that are critized by academics as insufficiently exact are often quite satisfactory for engineering purposes because the degree of error is within reasonable bounds.
- Conservative assumptions can be applied to CFD studies to account for the higher potential degree of error.

II. CFD as an alternative to wind tunnel modeling

Advantages	Discussion
• Full domain analysis	Wind tunnels need instruments to record wind speed at each discrete point. CFD by definition computes these variables throughout the whole study domain.
• Easy alternative analysis	CAD design of buildings in the CFD domain can be altered quickly and remodeling done immediately. Physical models require more time and effort for adjustments, especially if the design changes occur long after the initial wind tunnel modeling or the wind tunnel is booked for other projects.
• Cheaper overall	Same or lower cost and quicker turnover times to conduct the modeling in most cases.

• Better visualization of results	Results can be displayed in easy to understand graphical output. Wind tunnel photographs can not give nearly as much detail.
• Measuring wind direction, pollutant concentration, chemical reactions, radiation, etc. is difficult to do in a wind tunnel	CFD is generally more flexible at accounting for the unique aspects of each project.
• Proper wind tunnel facilities are rare.	Wind tunnel modeling requires large expensive equipment, which is why it is only conducted by several large international firms and universities. CFD modeling can be performed by local firms with better knowledge of local meteorological features.

Disadvantages	Discussion
• CFD is not an accepted industry standard	CFD is relatively new as a tool to assist with building analysis. Further research is improving the technology continually. Firms that use CFD stay up to date with advances in the science and software.
• CFD results can be erroneous	Studies have shown that CFD results do not coincide with real world results in certain circumstances. However, the problem areas are well known and the error is often small enough to be accounted for with conservative assumptions for engineering purposes. Common problems are: - Overproduction of turbulent kinetic energy in building wake - Over/underprediction of concentrations of pollutants at some locations - Improper handling of vortex shedding with steady state models
• Only experienced modelers should use the software.	A recent study demonstrated that results can vary significantly depending on the modeler, even using the same CFD code (Cowan, 1997)! Thorough knowledge of the atmospheric initialization and CFD meshing process is required to limit this.
• Projects cannot be too complex	The size of the project modeled is limited by the computing power and software used. A large wind tunnel is not so limited in the size and complexity of the model. Advancing computer technology continually expands the potential of CFD.
• Results are often better for less complex projects	The accuracy of the wind tunnel results is not dependent on the complexity of the geometry.

• CFD yields steady state solution, transient solution is more time consuming	Average wind field acceptable for certain applications including pollution dispersion and pedestrian winds (when turbulent kinetic energy is used to estimate gusts). Transient primary wind runs are used to locate time of worst conditions for conservative results.

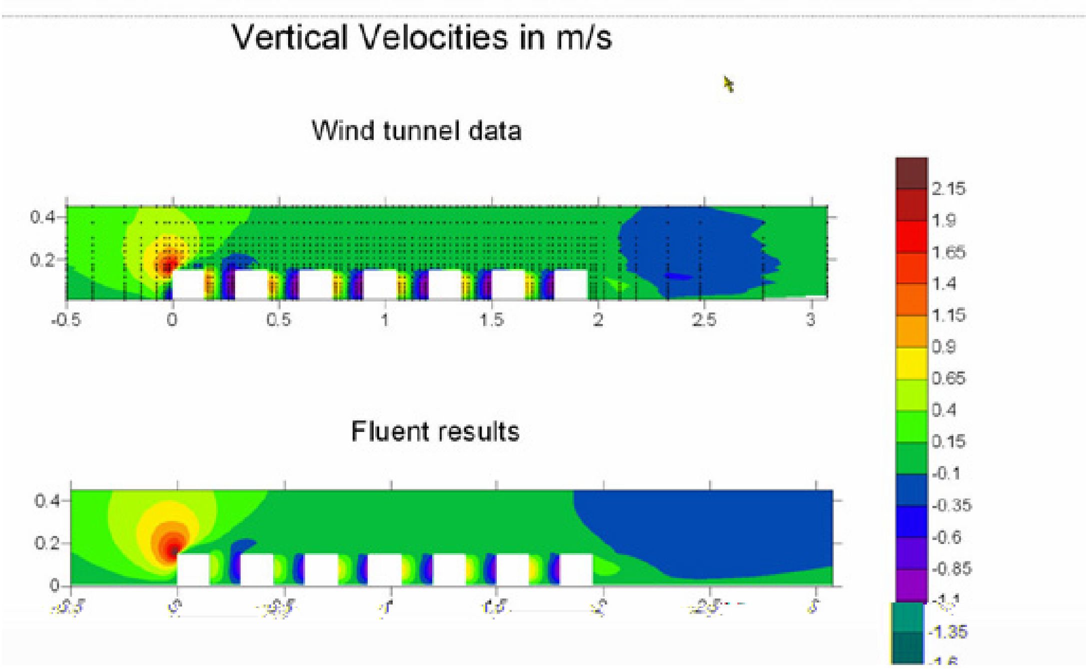
III. CFD vs. real-world and wind tunnel modeling results

Example 1: *Development and applications of CFD simulations in support of air quality studies involving buildings.* (Huber, 2004)

Paper recently presented at the joint Air and Waste Management Association/ American Meteorological Society conference on the urban environment. This paper outlined some of the current EPA research into the validation of CFD modeling for use in dispersion modeling in microenvironments.

The paper points out that CFD modeling often underpredicts turbulent kinetic energy (TKE) upwind of buildings and overpredicts TKE downwind of buildings, which is the common understanding at this time. Modified models are available that use various methods to correct this. TKE is important for determining wind gusts, recirculation zone size, and pollutant dispersion. However, the paper demonstrates that even though the model has some deficiencies, the results compare fairly well to experimental results. The paper illustrates the comparison of pollutant dispersion with graphs that show fairly insignificant deviation from experimental results.

The following graphic from the paper compares the performance of a modified CFD model and a wind tunnel in predicting elements of the flow that are important for determining pedestrian winds and pollutant dispersion.



Example 2: *A Comparison of Wind Tunnel and CFD Methods Applied to Natural Ventilation Design.* (Alexander, 1997)

This paper does not focus as much on the direct comparison of the CFD/wind-tunnel results, but the guidance that the results lead to. This is important because CFD is often used only as a tool to assist with the decision making of a project. Small variations in the results are rather insubstantial when it comes to true design guidance.

A large atrium at the south face of the building was designed to allow incoming outdoor winds to drive ventilating air movement in the atrium. However it was anticipated that, during stronger winds, flow reversal might occur due to wind pressure at the top of the atrium. Wind tunnel modeling demonstrated that flow reversal did occur during even during lighter winds; the design was flawed and required adjustment. Wind tunnel measurements were used to validate an addition to the building structure to prevent the flow reversal from occurring. The most useful change was the use of a "wing" to create lower pressures at the top of the atrium during windy periods, thus preventing the flow reversal from occurring. Different wing designs were tested until the most effective design was decided upon.

The entire process was repeated using CFD instead of a wind-tunnel. Though differences in the results were present, pressure gradients were relatively close, leading to confirmation of the flow reversal during high winds. The same selection of alternative wing designs were tested in the CFD model and the modeling resulted in the selection of the same alternative as finally selected during the wind-tunnel study. Therefore, both studies provided similar guidance by showing similar trends and indicating the same design solution.

Example 3: *Flow and Dispersion Around Storage Tanks: A Comparison Between Numerical and Wind Tunnel Studies.* (Fothergill, 2004)

This paper provides an in depth comparison of CFD results and windtunnel results for the variables involving turbulent kinetic energy around cubes and cylinders. It notes that higher accuracy can be achieved in CFD models if the calculation cell mesh is done carefully. It also notes that CFD is much more useful than the simplified EPA dispersion models for predicted wake concentrations.

Example 4: *The Numerical Wind Tunnel for Industrial Aerodynamics: Real or Virtual in the New Millennium?* (Stathopoulos, 2002)

This paper is a critical evaluation of the use of CFD as a replacement for the wind-tunnel. Its overall conclusion is that the use of CFD as a reliable accurate tool is promising, but currently falls short due to deviations from real world results. However, this paper references a number of comparison studies that generally support the use of CFD as a design tool. The author himself states that use of CFD for environmental wind effect problems has been shown to be generally comparable to wind-tunnel studies: "By and large the comparisons are satisfactory, at least for engineering problems." He references several environmental wind impact studies and their comparable results.

The author also explores pollutant dispersion using CFD and notes that modeling comparisons have not been able to accurately model some building recirculation zones when sources were located on roofs. However, he notes that other conditions have been modeled quite well.

Sources:

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Fothergill, C.E., Roberts, P.T., 2002. *Flow and Dispersion Around Storage Tanks: A Comparison Between Numerical and Wind Tunnel Studies.* Wind & Structures, Vol. 5, No.2-4 (2002), 89-100.

Huber, Alan, 2004. *Development and applications of CFD simulations in support of air quality studies involving buildings.* 13th Conf. on the App. of Air Poll. Met./5th AWMA Conf. on the Urban Env., August 25th, 2004.

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