

Title: Developing Virtual Engineering Tools for Hoop Swine Housing - **NPB #03-161**

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Abstract: Over the past century livestock housing facilities have evolved from traditional wooden barns to engineered structures made of plastic and steel. Although building materials have changed dramatically to match the needs of modern agriculture, the facility design process continues to lag considerably with farmers and consultants developing and adapting designs based on rules of thumb and past experience. The aerospace industry has developed computer models that accurately predict the airflow and temperature around an aircraft operating under specified conditions. This same type of computer model has been applied to swine production facilities to predict its airflow and temperature, but there is a steep learning curve associated with using these tools.

Virtual Engineering tools interface computational models with hog building geometry in a virtual reality environment making it possible for a livestock production specialist (farmer) to use the models and interactively alter the shape, size, operating conditions, or other characteristics of the components within the proposed system and see the impact of these changes on his/her production operation. A case study of Virtual Engineering was performed on a Hoop-Structure swine enclosure and a mechanically ventilated building. The mechanically ventilated hog building airflow model was exhibited using Virtual Engineering tools at the Iowa Pork Congress in January 2004.

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Introduction: Building design and ventilation plays a critical role in animal health, worker safety, and odor and gas emissions. All of these issues are attracting increasing attention in modern animal agriculture. However, feedback in the current design process is extremely slow, because investment in capital facilities has to be recovered before something new can be tried. As a result, construction opportunities and thus innovation can lag a generation or more at any individual farm. The tools in this project demonstrate how farmers can move beyond this traditional build and try technique.

Our approach retains farmer involvement in the facility design process but allow prototype testing and iterative design prior to the major capital investments. This is particularly important for new barn designs, where experience is lacking. We believe full development and implementation of these types of tools will yield large benefits to conventional designs, with virtual remodeling allowing farmers to meet emerging health, safety, and environmental criteria at minimum cost.

Approach: In this project, we developed an initial demonstration of computational models of agricultural buildings and a user center virtual engineering interface. In future proposals we will work to fully implement the tools initially developed in this project.

- *Computational models of agricultural buildings*—many questions loom about the quality of living conditions in animal confinement buildings, with implications for both production workers and the animals themselves. Computational models of agricultural buildings will identify areas in a building with poor ventilation, where a potential buildup of dangerous gases could occur. Ventilation system analysis can also determine ways to more effectively vent unwanted gases out of the building, with minimal air change requirements and heating demand. Air quality computational models will give users data on living conditions and provide a way to compare building designs and methods of raising animals. This project provided a realistic physical model of a hoop structure in order to demonstrate the potential of this approach.
- *A user centered virtual engineering interface*—as discussed earlier, one of the key goals is to develop tools that can directly help the livestock economy. To achieve this goal, these tools must be accessible to and usable by farmers who are specialists in livestock production but would not normally have access to these types of high fidelity modeling tools. By building these tools around a virtual engineering framework, we will couple the skills of these livestock production specialists with the modeling tools. This will open opportunities for new and innovative solutions to livestock production issues. This project demonstrated the potential of such an interface, illustrating to stakeholders the vision on which future proposals can be based.

The goal of virtual engineering is to provide a user-centered, first-person perspective, enabling the user (in this case a farmer) to interact with the engineered system in a natural way and to provide the user with a wide range of accessible tools. This requires a complete engineering model that includes the geometry, physics, and any quantitative or qualitative data from the real system. The user should be able to walk through the operating system and observe how it works, and how it responds to changes in design, operation, or any other modification. Interaction within the virtual environment should be through an easily understood interface, appropriate to the user's technical background and expertise, enabling the user to explore and discover unexpected but critical details about the behavior of the system. Similarly, engineering tools and software should fit naturally into the environment and allow the user to maintain her or his focus on the

engineering problem at hand. A key aim of virtual engineering is to engage the human capacity for complex evaluation and optimization. The key components of this environment include:

- User centered virtual reality visualization techniques
- Real-time analysis and engineering
- Coupling and integration of numerical models
- Integration of real processes into the virtual environment
- Decision support tools

As envisioned, a livestock production specialist (farmer) will be able to interactively alter the shape, size, operating conditions, or other characteristics of the components within the proposed system and see the impact of these changes on his/her production operation. This would include the impact on the critical parameters of mortality, production, and profits.

Once developed, access to these tools will be provided in at least two ways. With single stereo walls costing less than \$20,000 today, many organizations have access to some form of virtual reality. For example, Indian Hills Community College in Ottumwa, Iowa has a high end single wall system used for extension training in the bioprocessing industry. In recent discussions they have indicated that they are eager to work with the extension service to provide farmers access to this type of tool. Based on this, one model for delivery of these tools would be through extension service and community colleges. A second method of access could be through a web-based tool that would enable farmers to access some portion of the tool set.

Objectives:

1. Develop a computational fluid dynamics model of a swine hoop house facility, demonstrating the potential of virtual engineering to optimize building design to enhance animal comfort and minimize gaseous emissions.
2. Present this model at the Iowa Pork Congress, gaining exposure for the approach and feedback from producers.
3. Organize a series of on-campus virtual reality demonstrations to develop stakeholder interest for funding continued research in this area.

Materials & Methods: Three hoop structure configurations were modeled, winter conditions, summer conditions with back wall on, and summer conditions with back wall off. Geometry of an existing hoop structure with dimensions of dimensions of 72 ft x 30 ft floor with a 20 ft high ceiling, was modeled in Pro Engineer® and imported into StarCD® for meshing. The building was assumed to be empty except for two feeders located at the south end of the building. A box was generated around the grid that was three times the dimensions of the building. On two sides of the box, inlet conditions were applied to simulate wind. The grid was broken down into blocks that were around 1 cubic foot in size. No temperature data was used in the model. The air was assumed to be at standard temperature and pressure. The building's longer dimension was aligned with north south having the open end with the feeders facing south.

A tunnel ventilated building was also modeled. The building geometry of the building was 150 feet x 40 ft wide, with a slatted floor above a deep pit for manure storage. The ceiling is 8 ft from the slats. Walls were solid. Small feeders exist in rows

on both sides of the building. Large openings and an assortment of large fans face opposite each other on the short sides of the building creating the tunnel ventilation effect. Four smaller fans operate below the slats to exhaust hazardous gas buildup from the manure.

The immediate volume surrounding the building was meshed in 1 ft³ cells. Cell size used for volume outside the building was quickly ramped up to save on computations. The control volume surrounding the building was 3 times the dimensions of the building. This distance eliminated boundary effects that may be caused by the wall. The building's longer dimension was aligned with west to east with the fans blowing east. The surface of the pit was located 2 ft below the slats surface. No effects from pig geometry, heat, or slats were included in the model.

Typical wind velocity in July in Ames, Iowa was used for boundary conditions on the hoop building. Hourly wind speed data was obtained from the Iowa State University Mesonet (<http://mesonet.agron.iastate.edu>). A wind speed of 7mph from the southwest was used for summer conditions and a wind of 7 mph from the northwest was used for winter conditions.

Computational fluid dynamics (CFD) was used to predict the flow of air around the hoop structure for three configurations. The CFD package STARCD used the Navier Stokes equations to model the airflow through the hoop structure. STARCD uses the implicit SIMPLE method to solve the algebraic finite-volume equations. The high-Reynolds K-E turbulence model was assumed for the conditions, assuming most of the grid would have a high Reynolds number. The high K-E model makes assumptions to avoid having a computationally expensive tight mesh along the wall boundaries.

VE_Suite was used to visualize the CFD results in a variety of virtual reality systems. VE_Suite is an open source virtual engineering software package that works with VR Juggler. The system used that is most applicable to swine producers was a single wall virtual reality system that consisted of two off-shelf Dell computers, and two off-shelf projectors.

Results:

I. The hoop swine house facility was modeled in various configurations for summer airflow. Examples of results are shown in the following Figures.

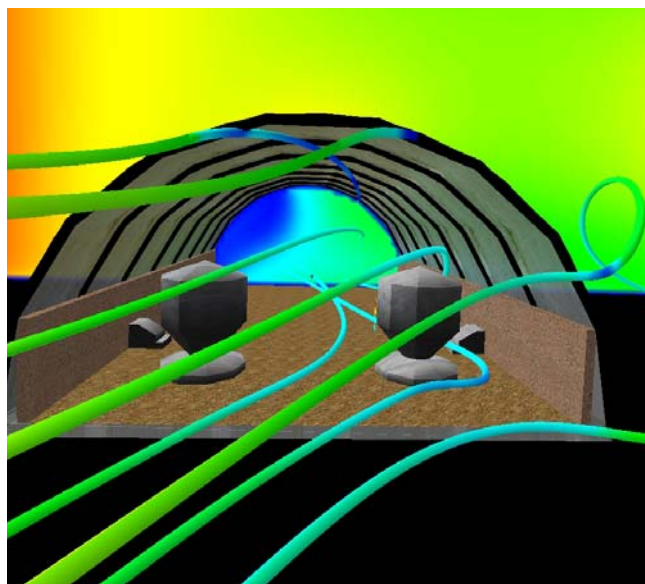


Fig. 1, Velocity profile and streamlines for summer airflow in hoop structure shown in Virtual Engineering environment.

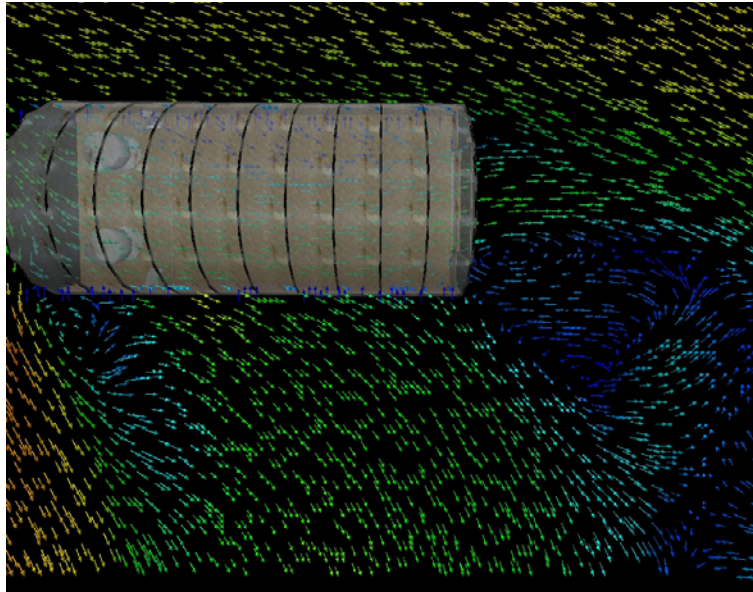


Fig. 2, Velocity vectors for summer airflow in hoop structure with back wall shown in Virtual Engineering environment.

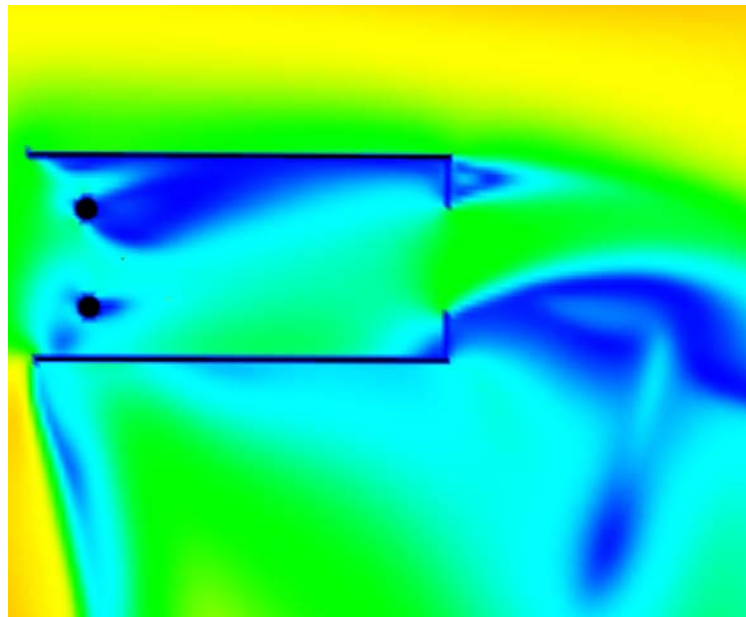


Fig. 3, Velocity profile from floor for summer airflow through hoop structure shown in Virtual Engineering environment. Cutting plane is 12 inches above the floor.

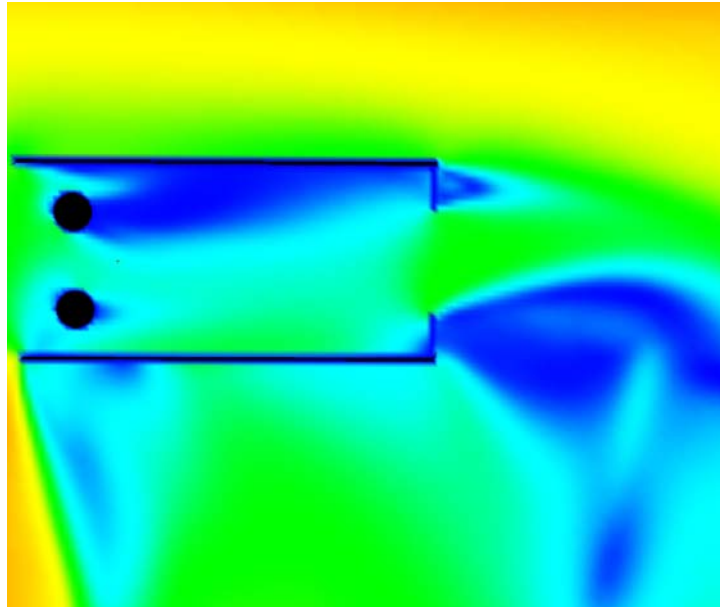


Fig. 4, Velocity profile from floor for summer airflow through hoop structure shown in Virtual Engineering environment. Cutting plane is 36 inches above the floor.

The following Figures show airflow in a mechanically ventilated building.

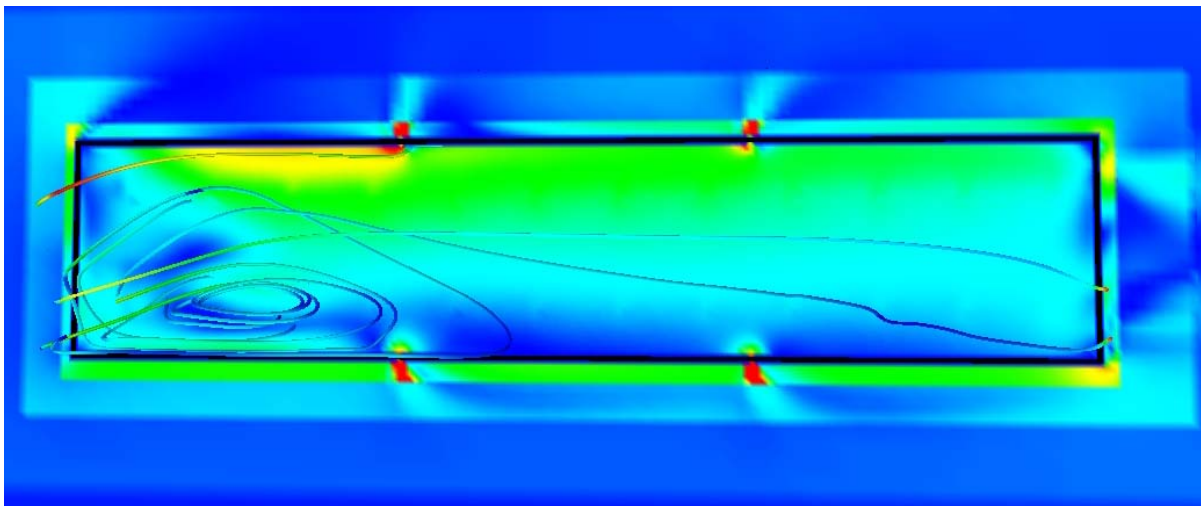


Fig. 5, Velocity profile and a few streamlines of airflow in cutting plane 6 inches above manure in deep pit, tunnel ventilated hog building

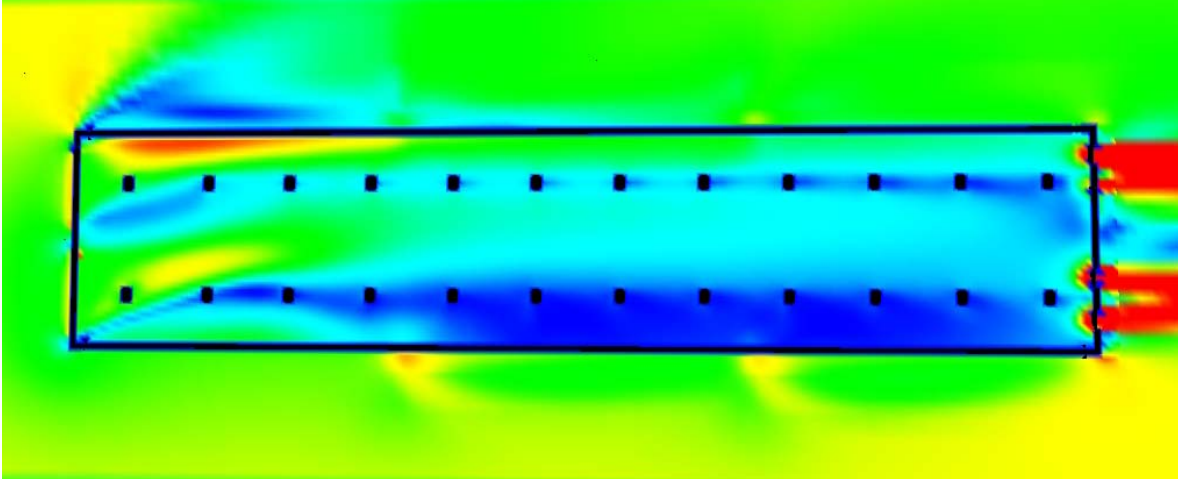


Fig. 6, Velocity profile of airflow in cutting plane 18 inches above slats in tunnel ventilated hog building

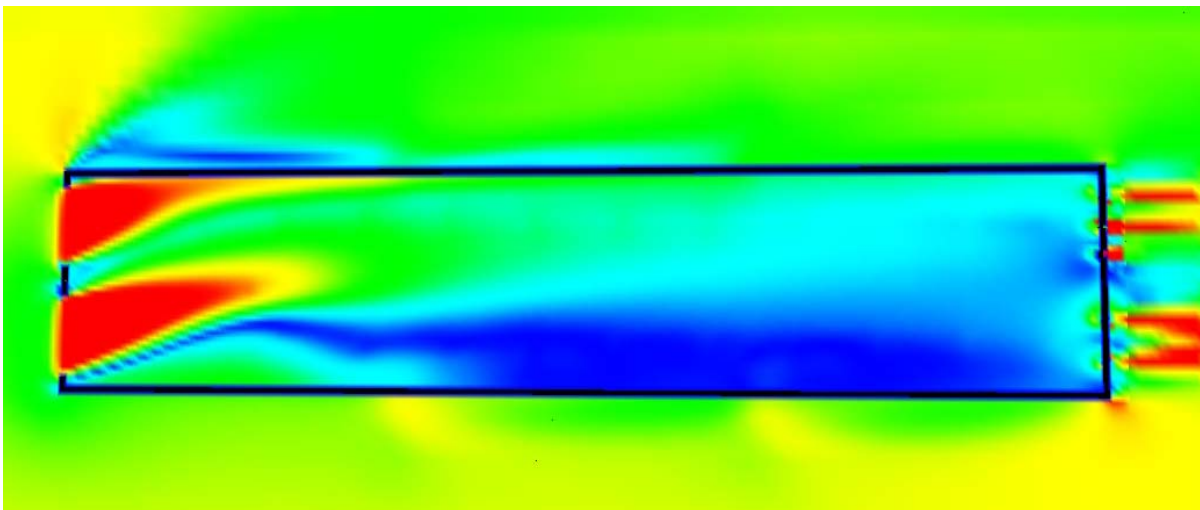


Fig. 7, Velocity profile of airflow in cutting plane 12 inches below ceiling in tunnel ventilated hog building

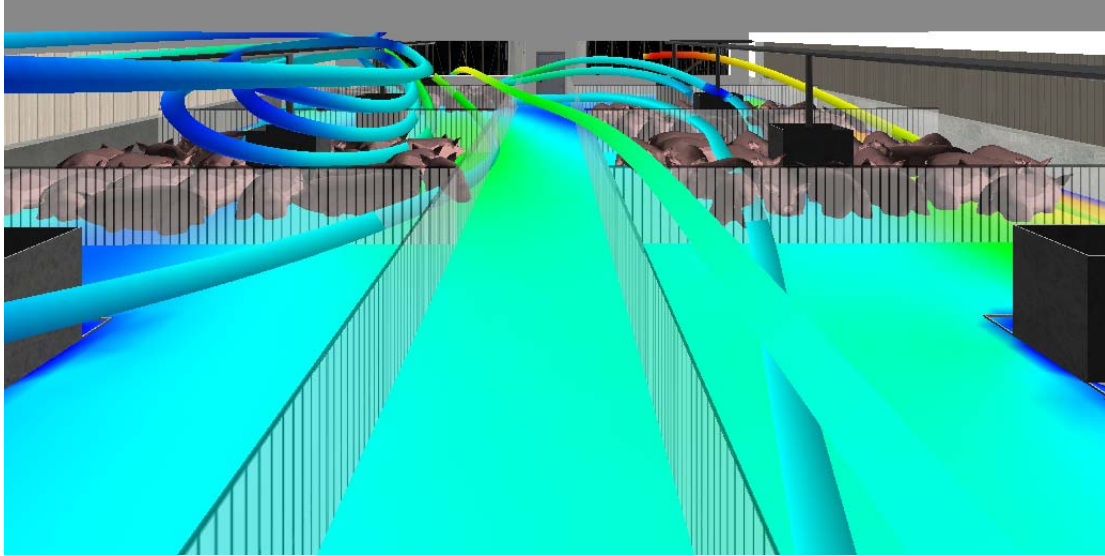


Fig. 8, Velocity profile and streamlines of airflow in tunnel ventilated hog building in Virtual Engineering environment

II. The mechanically ventilated hog building Virtual Engineering model was presented on a portable single wall Virtual Reality system at the 2004 Iowa Pork Congress. An estimated 200 people participated in Virtual Engineering demonstrations at the event. Feedback and contact information was collected for future research projects.

III. Approximately nine Virtual Engineering hog building demonstrations have been given at Iowa State University to people directly involved with the pork industry. Members from the National Pork Board staff, Pork Board committees, ISU swine specialists, and ISU agricultural engineering professors have toured the virtual hog building and given feedback.

Discussion: This project demonstrated the viability of developing a user centered design tool for modeling, operating, and designing new construction of swine production systems. The proposed were well received at both the Pork Congress and the various user groups that visited ISU. Many of the users commented on how easily the computational results could be understood.

Examples of the observation that were made by users include:

- The corners of a tunnel ventilated building are likely to cause poor ventilation along the windward side of the building as shown in Figures 5-7. Recirculation occurs in four pens on the windward side. The recirculation area continues throughout the building along the south wall. The three top views of the building show how much air flow occurs near the ceiling. With this knowledge, a farmer could try to redirect some of that airflow towards the pigs with some kind of partitioning.
- The hoop structure building figures for summer flow show that the feeders play a role in decreasing building ventilation. Farmers should consider using smaller

feeders or feeders with a smaller cross area to face the opening of the hoop structure.

- The back wall on the hoop structure for summer conditions creates much recirculation. This information is important to someone attempting to measure emissions from a hoop structure. For winter, the small vent at the top of the back wall creates a swirling motion around the building. This may help to explain why pigs choose the locations they pick to bury down in the bedding.
- The technology developed at this point allows us to create simple models of hog buildings. This technology immediately shows that there is a need for models to determine the most accurate spots for emissions sampling. It also shows that there is a lot of interest in having further developed models that account for more temperature effects, emissions, leaky curtains, and aerosol disease tracking.

Lay Interpretation:

When Pigs Fly

Would you fly on airplane that hadn't been tested? Neither would anyone else. Over the past 3 decades, researchers have developed very accurate numerical models for airflow around an airplane geometry that predict how well their plane design will fly before ever building it. Until recently, this type of modeling was limited to research labs with supercomputers, but decreases in cost of computers and increases in their speed have made these modeling techniques accessible to people with lower budgets. Now, would you build a new hog confinement without testing it? Researchers in the Agricultural and Mechanical Engineering Iowa State University have applied the same numerical models used on airplanes to swine production systems to predict airflow, temperature, and air quality in and around the building. These models and their results are typically tedious and difficult to operate and require a computer expert/engineer to operate, but not many engineers have been in a hog building. So, ISU is developing a suite of tools that can turn a farmer into a Virtual Engineer. Virtual Engineering tools interface computational models with hog building geometry in a virtual reality environment making it possible for a livestock production specialist (farmer) to use the models and interactively alter the shape, size, operating conditions, or other characteristics of the components within the proposed system and immediately see the impact of these changes on his/her production operation. Virtual Engineering tools in the hands of hog building experts means better designs, better stewardship, known results before changing an existing building, and happier hogs. So, will pigs fly? No, but we can make sure the design of their building will be a success.

This project was displayed at the 2004 Iowa Pork Congress. Research efforts are ongoing. Please contact Joe Hynek, jhynek@iastate.edu, 515-294-5289 if you have any questions. This project was funded by the National Pork Board.