Designing **COMFORT** into Clothing

Toyobo develops a pressure simulation system with Abaqus FEA for evaluating realistic garment performance

While fashion design grabs the headlines in the apparel industry, all of us know that comfort, reliability, and performance are equally important considerations in our clothing purchases. Is your underwear too tight? Is your bathing suit too constricting? Do your pants bind when you walk? Traditionally, these questions have been addressed through human perception studies —psychology and physiology—as well as some limited pressure-testing systems. But in an industry which is so large and diverse, it was only a matter of time before someone applied the science of realistic simulation to the study of clothing comfort.

Clothing pressure, or the contact pressure between a garment and the skin, is one of the indicators used for evaluating the comfort of clothing, along with other variables such as thermal characteristics and moisture transfer of fibers and textiles.

Expertise in the clothing field comes naturally to Toyobo Co., Ltd., which was founded as a textile company over 125 years ago and is now a versatile, multi-national company based in Osaka, Japan. In addition to the research and development of textiles, Toyobo works with other high-performance materials and films, such as polymers, industrial materials, and materials for the life sciences.

"In fields such as clothing, healthcare, and sports, a simple and accurate understanding of the clothing pressure and clothing pressure distribution during body movements is essential to the design of clothing and clothing materials," says Chisato Nonomura, Ph.D., manager of the Computational Research Group at Toyobo. As part of the company's research and development into fabrics and textiles, engineers at Toyobo have developed a simulation system that measures the pressure of clothing against the skin. This analysis is useful in the development of fabrics and the design of clothing such as underwear, pantyhose, sportswear, and other tight-fitting apparel to make them as comfortable as possible for the wearer. Nonomura adds, "The adoption of realistic simulation is indispensable to efficiently design garments that create optimal clothing pressure."

This simulation system—as well as subsequent studies on material modeling carried out by Hirohisa Noguchi Prof. Dr. Eng/Masato Tanaka Ph.D at Keio University, and Takaya Kobayashi/Shuya Oi at Mechanical Design & Analysis Corporation—were supported by Japan's Ministry of Economy, Trade and Industry.

To perform their pressure analyses, Toyobo chose Abaqus Finite Element Analysis (FEA) software from SIMULIA, the Dassault Systèmes brand for realistic simulation. The company estimates that by using simulation it reduced the time and cost of their product design process by as much as 80 to 90 percent.

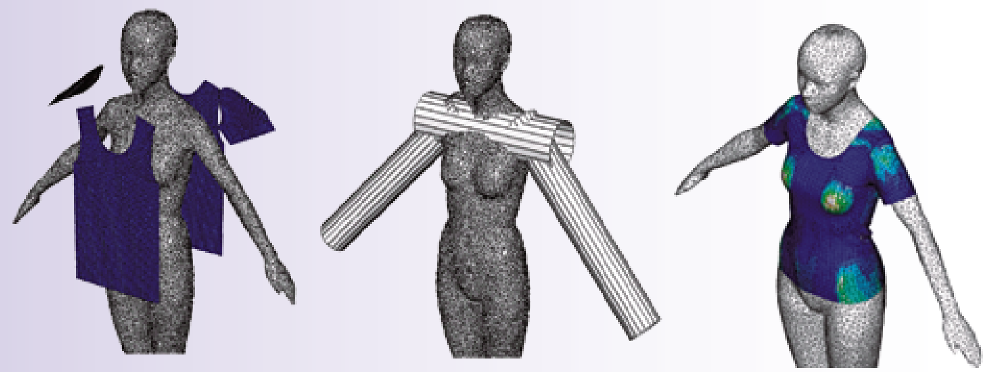

Figure 1. Abaqus finite element analysis of clothing pressure: (left) sewing pattern placement; (middle) intermediate body; (right) contact pressures when wearing garment

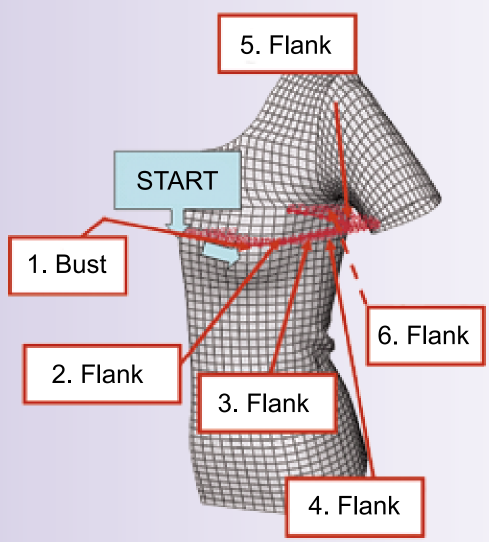

Figure 2. Location of air pressure measurements for a t-shirt, taken during an experiment.

Figure 3. Clothing pressure distribution from Abaqus simulation results for a t-shirt.

Creating Body and Sewing Pattern Models

To create the virtual human body model for the pressure simulation in Abaqus, engineers at Toyobo used a dummy (WD-20), supplied by Nanasai, Co., Ltd. that corresponded to an average 20-year old Japanese woman. They obtained the surface data from a 3D measurement taken from the dummy and created the virtual body in Abaqus as a rigid model. To create FEA models of the garments themselves, the team selected two types of clothing: a short-sleeved, tight-fitting knitted undershirt made of a blend of polyester and polyolefin; and a pair of pants, commonly worn by women for sports such as golf, made of a blend of nylon and polyurethane. Paper sewing patterns of the shirt and pants were used as the basis for the clothing models.

Having created CAD models for the body and the clothing, the engineering team imported both into I-DEAS for meshing, then created Abaqus input files and added the analysis attributes. They used the rigid element R3D3 for the body and the shell element S4R for the sewing pattern models, using approximately 18,400 elements for the body, 3400 for the pants, and 4300 for the t-shirt. (see Figure 1).

Modeling Fabric is Tricky

Fabrics and textiles do not behave like a homogenous material such as steel, which responds identically to a load applied in any direction. Fabrics are varied and come in many forms—woven or knitted, made from natural or synthetic fibers (such as cotton, wool, polyesters, or acrylics). Because the properties of fabrics are complex, creating a model that accurately represents their behavior without being too detailed is complicated.

Knitted fabric, for example, demonstrates hysteresis in uniaxial extension and unloading (see Figure 2). In addition, its behavior differs depending on the tensile direction, indicating orthotropy. So, in order to simplify the modeling of the fabric, the Toyobo engineering team needed to make some assumptions. For the purposes of the model, they ignored hysteresis, extracted only extension data, and assumed nonlinear elastic behavior. They also ignored the effect of material constriction, a characteristic of uniaxial extension, and to account for anisotropy, they used a Neo-Hookean hyperelastic body as the matrix (see Figure 3). In addition, they assumed the material was of uniform thickness and used non-compression conditions for the model.

Woven fabric behaves differently than knitted. It has fibers that are oriented in two directions—the warp, like longitude on a map, runs vertically, while the weft runs horizontally, like latitude. As the fabric is stretched in either of these directions—north/south or east/west—or on the bias at 45 degrees, it demonstrates different characteristics. To model this behavior, the engineering team used a feature in Abaqus called rebar layers, which functions to reinforce the material in a uniaxial direction—in the same way that metal rebar is used to reinforce concrete.While the rebar feature was developed to model structural concrete, the team developed a subroutine (UHYPEL) so that it could also be used to accurately represent the behavior of fabrics.

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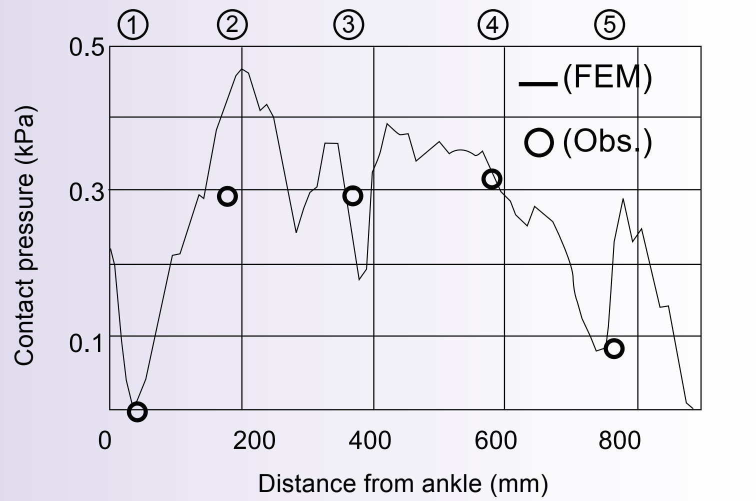

Figure 4. Chart shows validation of pants pressure simulation with experimental data collected from air pressure measurements.

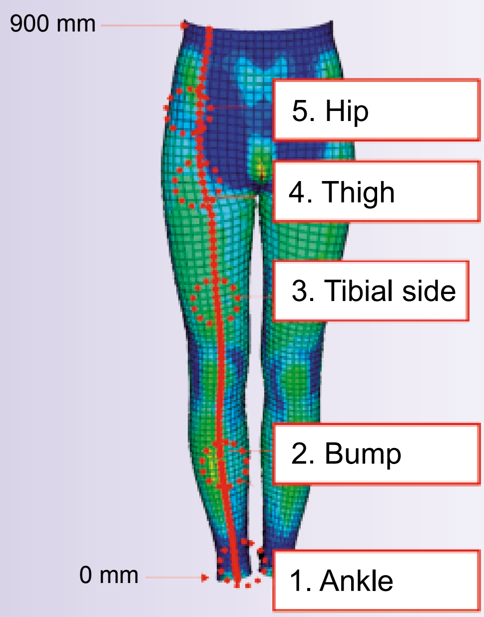

Figure 5. Location of air pressure measurements for pants, taken during experiment.

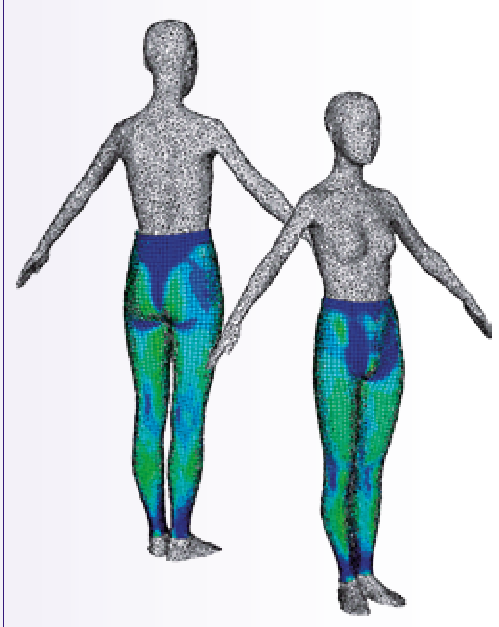

Figure 6. Clothing pressure distribution from simulation results for pants.

In the model, the shell is a hyperelastic matrix to which rebar, or reinforcement, is added. Using data that resulted from elongation tests in the warp, weft, and bias directions, the team created a fabric model that allowed for the simple expression of orthotropy and nonlinearity. Following input of specific fiber material properties, engineers determined that the model was representative of both woven and knitted fabrics, although knitted fabrics, with their inherent loops of fibers, demonstrate more complicated behaviors.

Simulating and Validating Clothing Contact

Toyobo chose Abaqus, Nonomura says, because "The FEA software has lots of material options and robust, nonlinear analysis capabilities." For this analysis, the simulation flow was relatively simple. Engineers first imported—from 3D measurement scanning and CAD systems—the human body and sewing pattern data, then placed the patterns on the front and back of the body model, and finally moved the patterns closer to the body, analyzing contact and pressure (see Figure 4). "In Abaqus, it was easy to implement new material models, and also to solve the body-sewing pattern contact problem," says Nonomura. The simulation was done on an HP Xeon workstation (3.6Ghz) and took about six hours for both the t-shirt and the pants.

To validate the simulation results, the Toyobo team used an air-pressure measurement device, a long-standing technique in the industry. This system measures clothing pressure by calculating the difference between atmospheric pressure and the pressure pneumatically transmitted from air packs attached to parts of the body where the clothing contacts the skin (see Figure 5). For the t-shirt analysis, pressure was calculated on the bust, flank (side of chest), and navel regions of the body. For the pants analysis, pressure was calculated for the ankle, shin, knee, thigh, and hip. When comparing the two sets of data, the team found that the simulation results accurately reproduced the actual experimental measurements for both the t-shirt and the pants (see Figure 6).

More Comfortable Clothing Through Simulation

"In an industry that is old and quite conservative, it can be difficult to introduce new technologies," says Nonomura. Using the traditional garment development process—from fabric, to sewing pattern, to sewing, to wearing, to measurement—can take a few months, and even more time if there are subsequent changes in the design. Using simulation condenses the entire process: from fabric/sewing pattern, to simulation analysis, to sewing. "Realistic simulation saves on sewing effort and significantly reduces the time and cost of the process," points out Nonomura. "What's more, we can continue to enhance our simulation system—most recently by using anisotropic hyperelastic shells with a polyconvex strain energy function—for even more accurate fabric modeling of the interaction between the warp and the weft."

With new fabrics and fibers being engineered continually and consumers becoming more demanding about the comfort of their clothing, the value of simulation cannot be ignored, Nonomura adds. "A lot of companies in the business of developing fabric, fiber, and garment designs can get tremendous benefit from employing simulation."

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