NIST

Respirator Modeling: Fit (LS-DYNA) and Function (CFdesign)

Engineering Safety

Respirator masks have historically been designed with lots of silicone rubber to slop over a range of faces. This works adequately for many facial sizes but not for all. For face profiles that don't follow the norm, the use of respirators can lead to a false sense of security due to air leakage or a contamination threat. The National Institute of Science and Technology has been engaged in a multi-year program to improve the safety and effectiveness of full-face respirator masks. To meet some impending deadlines on this project, Predictive Engineering was competitively awarded an investigative project to study the fit and function of an industry standard respirator mask. A key finding of this work was that the modeling of human skin is best represented as a flexible bag of viscous fluid and not as an semi-elastic solid as has been done in prior work external to NIST. CFD studies also indicated that air flow within the respirator mask is not optimized and could be improved with some minor geometric changes. These and other findings are scheduled for publication under the NIST banner with a gracious co-authorship to Predictive Engineering for meeting project goals on time and on target.

Model Details: The project involved the complete analysis of the fitting process between a respirator mask and a human head. The respirator seal geometry was provided as IGES data generated from laser scanning process over the original respirator. Head geometry was likewise provided in a similar format. Femap was able to parse the skins together and create a clean manifold skin that facilitated a quad-dominate mesh for the respirator and likewise a smooth tet mesh for the head. This model was then submitted to LS-DYNA for a complete fit and contact analysis. The mast was actually pulled against the face and allowed to seal. Seal pressures were then generated.

For functional analysis, a transient CFD analysis was performed using CFdesign. This was quite tricky since the original geometry was not quite representative of the flow passage within the respirator. With some cleanup help from Femap, a clean model was then submitted to CFdesign. It was impressive how well CFdesign handled the transient flow conditions for inhalation and exhalation through the use of ramped flow-rate curves. CFD results were checked for convergence with the mass balance error under 1%.

Analysis Tools: The model was constructed in Femap v10.1.1 and analyzed with LS-DYNA V5.0 and CFdesign v2010

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One can imagine that a loose fitting mask is actually more dangerous than no mask at all. Mask fit is something of a dirty secret in the respirator business since many non-standard facial sizes (e.g., young children) are problematic to obtain air-tight seals without pulling so hard on the straps that severe discomfort quickly incurs.

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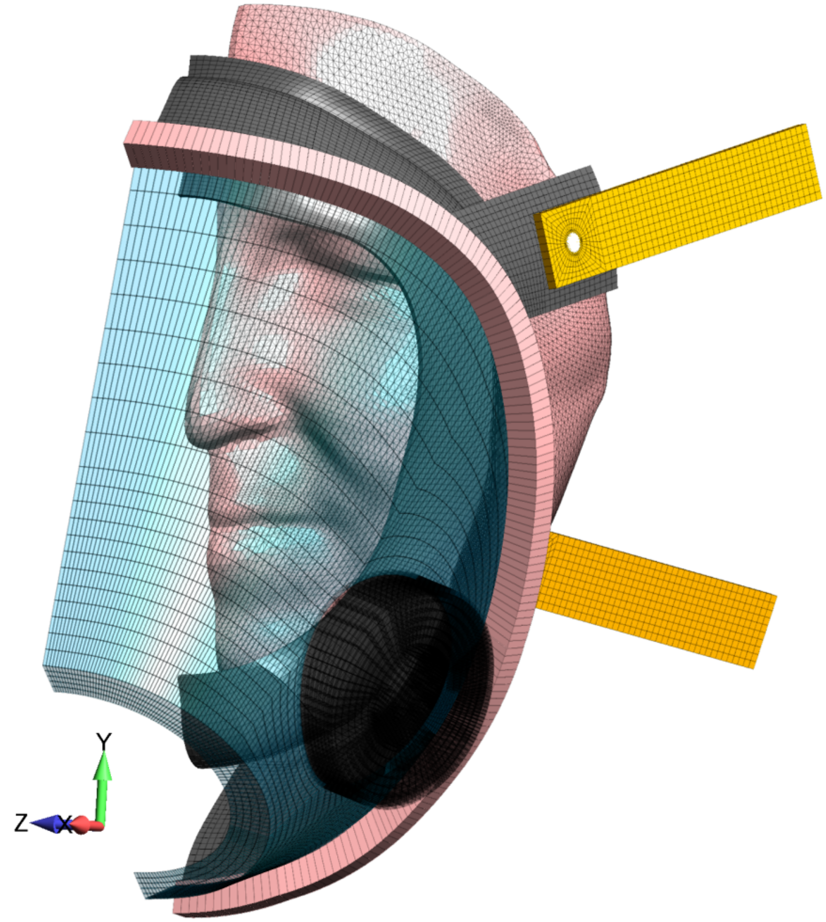

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The contact behavior between the silicone rubber respirator seal and human skin was analyzed using LS-DYNA. The same constitutive model for the silicone rubber and human skin (*mat 181 simplified rubber) was used, albeit with different properties.

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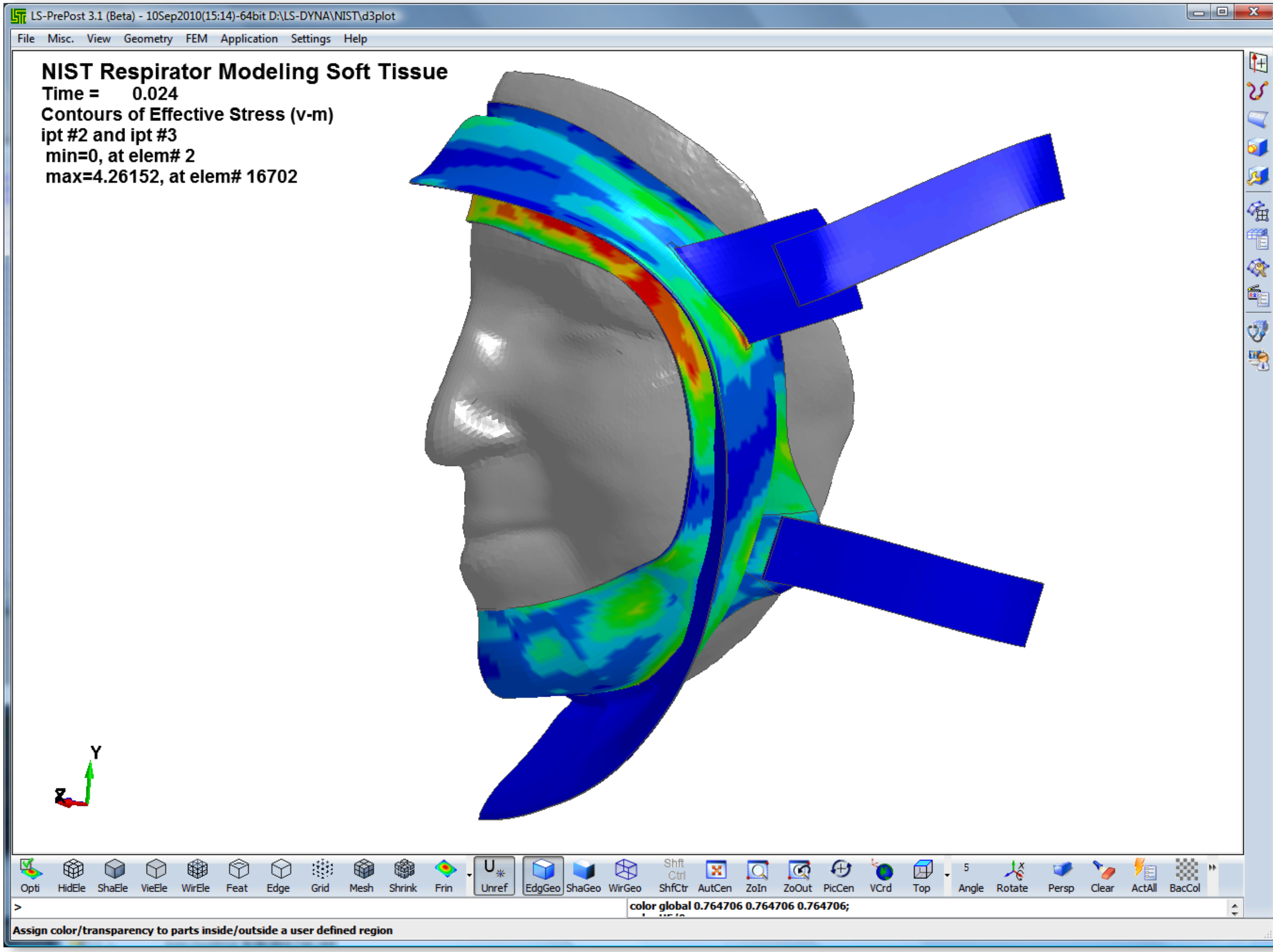

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The LS-DYNA run pushes the head against the silicone seal as the straps are being pulled backward with a displacement function. Fit pressures were calculated at various strap pressures to optimize the fit function of the respirator mask.

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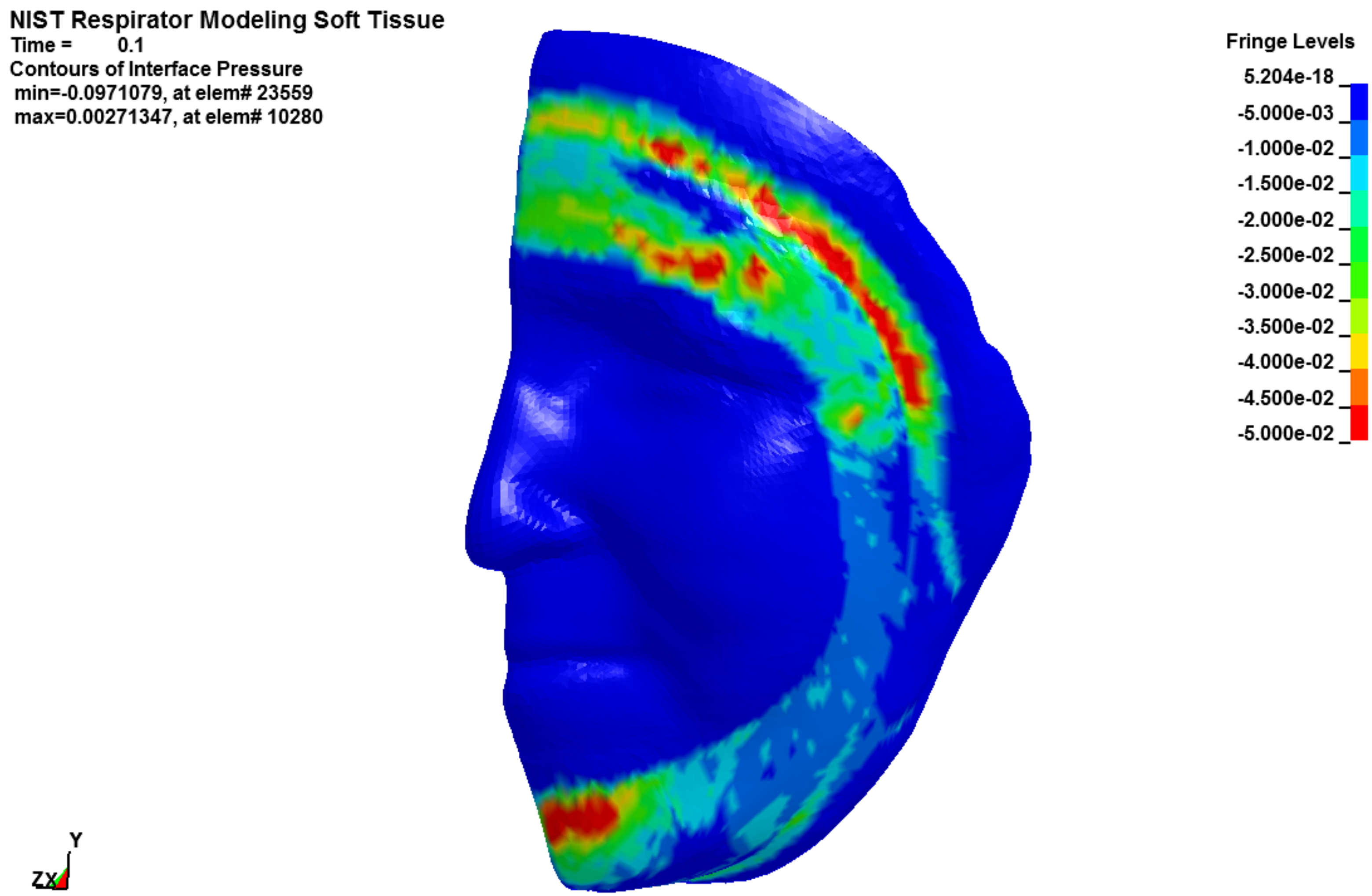

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Contact pressures can be generated within LS-DYNA through the use of a specialized keyword that provides the true pressure field generated during contact between the silicone rubber and pseudo human skin.

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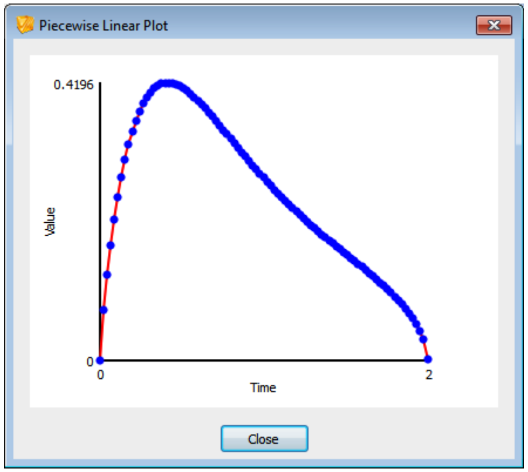

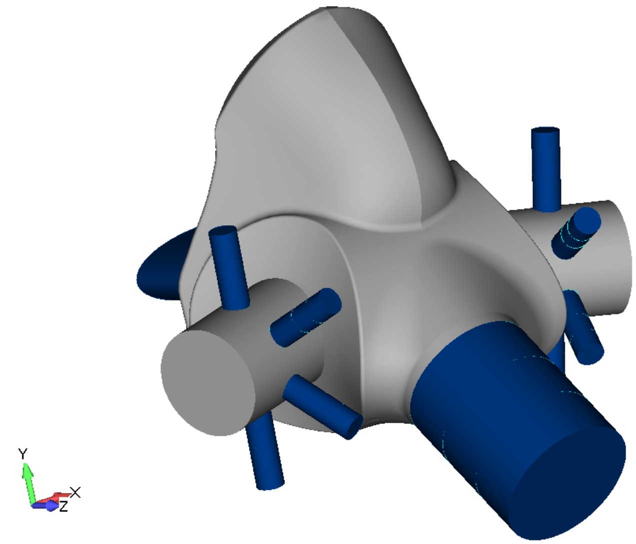

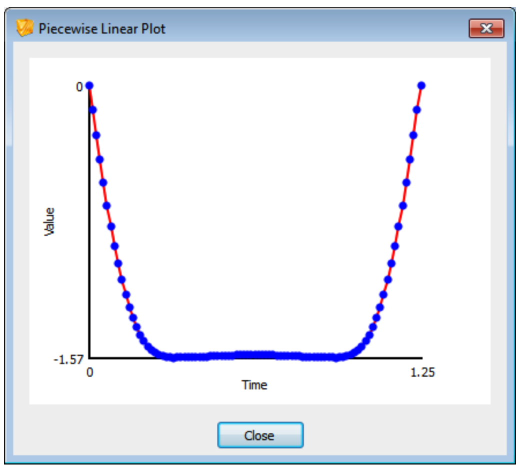

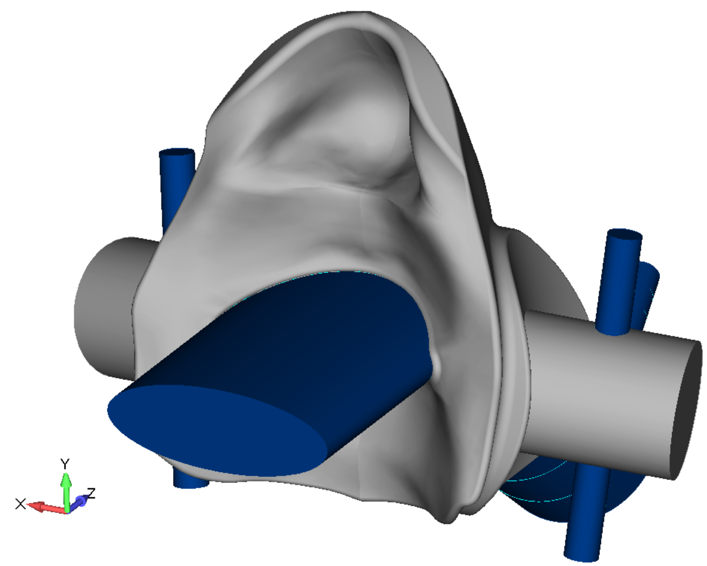

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The transient inhalation and exhalation curves were used as the boundary conditions for the CFD analysis. The geometry on the right represents the starting point for the transient flow analysis. Extensions to the original respirator geometry were added within Femap to prevent undesired flow turbulence.

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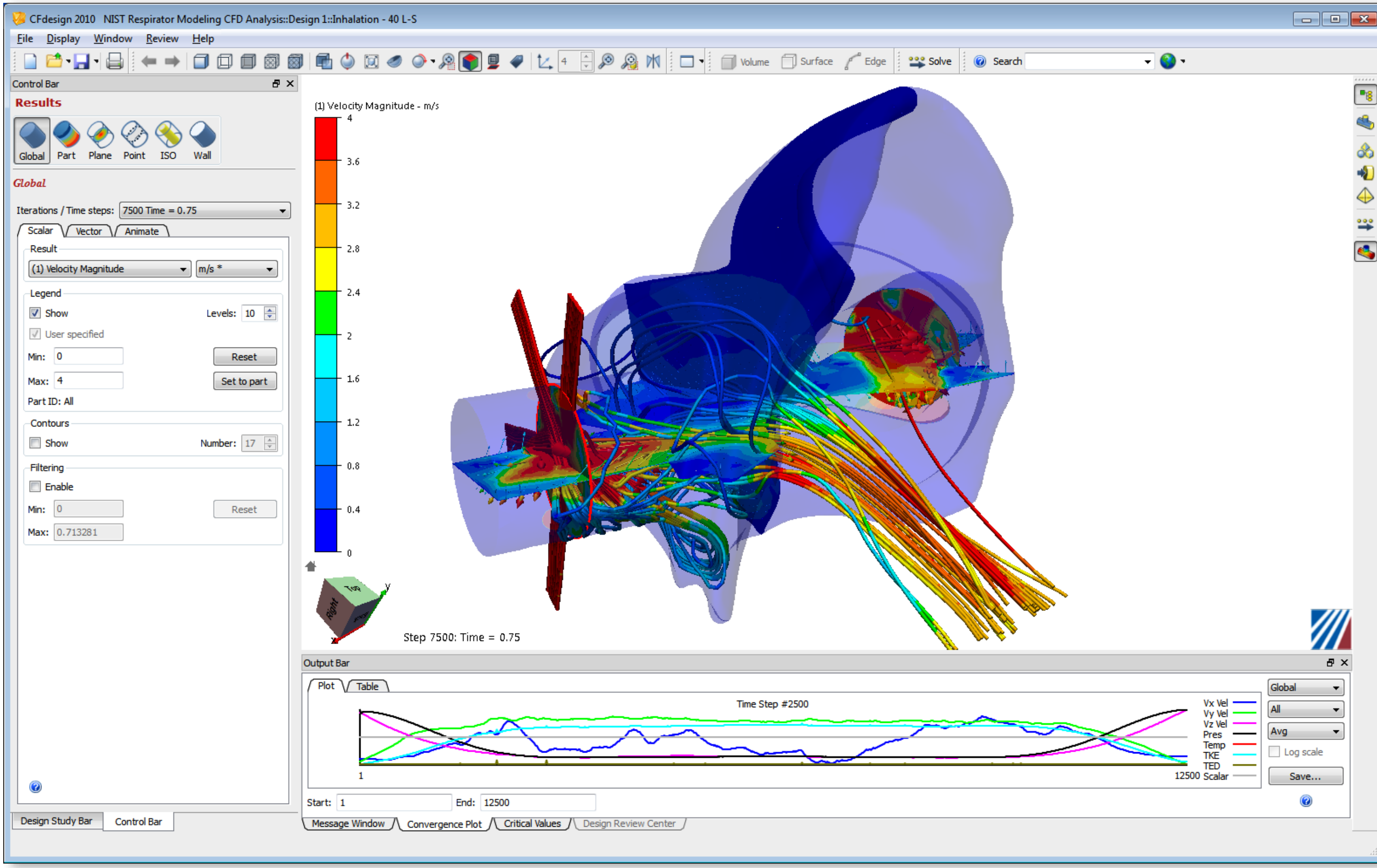

The inhalation model at the working respiration rate is shown above. The convergence traces at the bottom of the image shows a stable transient analysis run with little variance during the solution. The graphic above shows the flow lines at a time of 0.75 second.

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