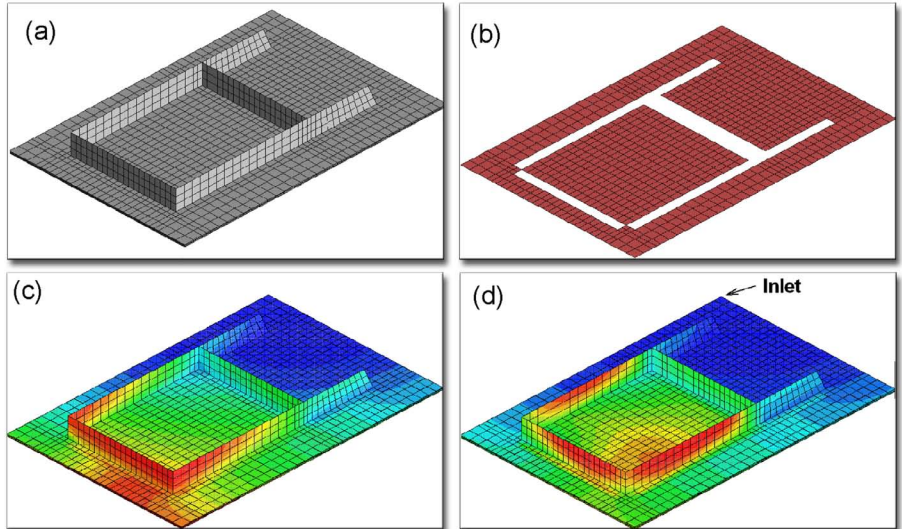


Liquid Injection Molding Simulation (LIMS)

Liquid Injection Molding Simulation (LIMS) is a software tool that simulates the mold filling stage of resin transfer molding (RTM) and related processes by modeling flow through porous media by Finite Element/Control Volume Method. It provides a cost-effective way to verify and optimize mold design by providing a “virtual” mold filling process to avoid time- and resource-consuming trial and error in physical reality. LIMS has been successfully used to design and simulate intelligent or adaptive filling processes that utilizes sensors mounted on the part and controllable injection hardware, either as a stand-alone program or as a simulation engine for other programs.

LIMS Features

The simulation allows the user to monitor flow progression, pressure distribution, and inflow rates during the mold filling process. Various inlet parameters, including location, can be changed during the simulated filling. A number of other effects, such as "race-tracking" -- the tendency for resin to flow much differently

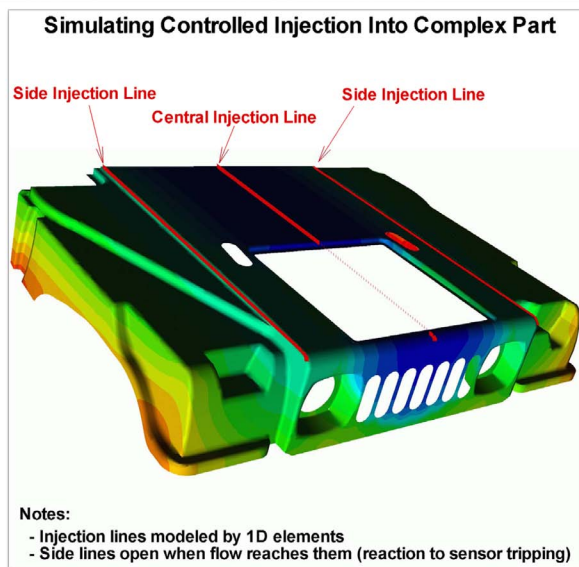


Simulation of VARTM injection into a ribbed panel: (a) part as a combined 3D/2D mesh (b) 2D model of distribution media (c)(d) flowfronts for different permeability values.

around corners where draped preforms have folded -- can also be modeled.

The built-in scripting interpreter allows the user to tailor the simulation to address many special issues. Scripts can access the parameters during the simulation and modify the simulation parameters as needed. It is even possible to modify the material data during the simulation. This allows the user to simulate complex filling schemes such as those using adaptive controls. For example, the evaluation of fiber tow saturation through a set of scripts is available with LIMS distribution.

The program offers three interface options. First, the provided graphical user interface (LimsUI) allows the user to comfortably modify the material and injection parameters to run simulation and to view the simulation results. This interface is tailored to the particular needs of resin flow modeling. It allows one to accomplish most common operations, including creating of the distribution/racetracking channels and distribution media layers by point-and-click. It also automatically runs the simulation according to the most common scenarios. Second, the command console allows power user to fully harness the LIMS BASIC interpreter either by directly typing the commands or by using LBASIC scripts. This offers the user access to the full power of the simulation engine making it possible to model LCM process variations, introduce optimization and process control. Third, for those interested in utilizing the simulation engine in their own program, say for the purpose of optimization, there is a slave version and dynamically linkable library to be included in the user program.



Simulation of controlled sequential injection into a composite vehicle hood.

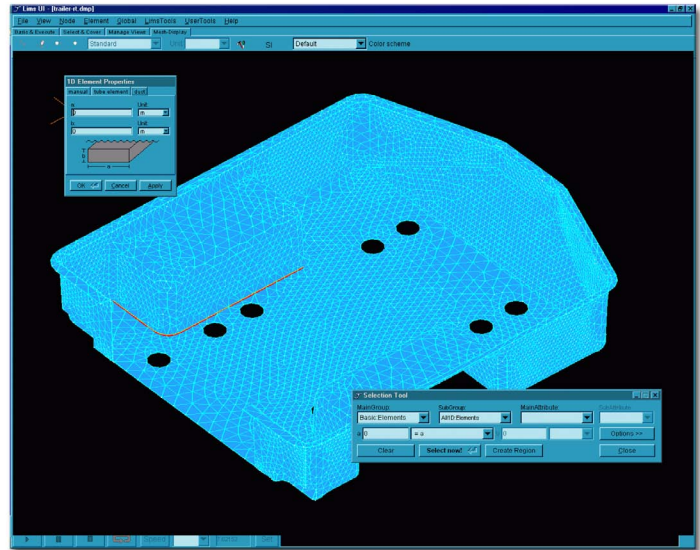
Specific Capabilities

- The incremental solution algorithm provides fast simulated filling. Problems with a few thousand degrees of freedom solve within seconds on usual personal workstation (~3GHz Intel i7).
- The mold geometry may be a three-dimensional solid, a three-dimensional shell, or any combination of both. One-dimensional "channel" elements may be added to any geometry to simulate phenomena like systems of injection tubes or racetracking. Two dimensional surface may be added to three-dimensional mesh to model highly permeable distribution media. LimsUI allows user to add such features to the pre-existing mesh.
- Multiple injection gates, vents, sensors, and inserts are allowed. These may be modified as the filling simulation progresses, allowing for example opening and closing of injection gates and vents as needed.
- The role of fabric deformation during the preforming stage may be included using additional code, available from the University of Delaware for the simulation of draping (DRAPE) and permeability predictions (PERM). This code is easily integrated with LIMS.
- The user may control the simulation through a built-in programming

language. The program can monitor the filling and simulate on-the-fly control.

- All solution data is available to the interpreter during the simulation, thus effectively simulating a large array of sensors. These "numerical" sensors can be used to design or verify mold filling control strategies, as gates and vents can be adjusted in response to signals sent by these sensors. Even the material data may be modified, allowing the user to model processes, such as Compression Resin Transfer Molding (CRTM).
- Dry spot prediction is available.
- Output of the results is available at any time during execution of the program. One may either take the over-all snapshot in any given instant, or track the individual values of interest through the filling process.
- On Windows platforms, dynamic link libraries are provided for other programs to run and control LIMS simulation and exchange data with the simulation in efficient manner. Interface to Labview and Matlab has been implemented by the University of Delaware.

• Graphical user interface is available. It is tailored toward the specific needs of liquid composite molding. It facilitates modifications of preform properties, generation of additional race-tracking and distribution media geometry, execution of



LimsUI Graphical User Interface. A racetracking channel is being added to a mesh of automotive trailer.

filling simulation(s) and the display of results.

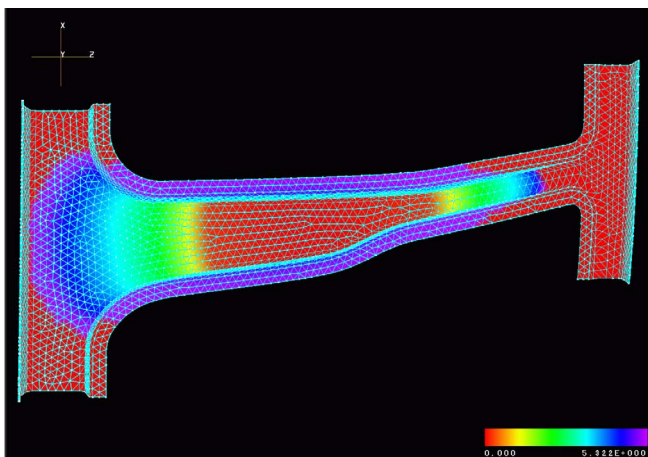
- Input files can be prepared in I-DEAS, PATRAN or any program that supports export to ABACUS input file. Output is available through its graphical user interface, TECPLOT package or free open source GMSH postprocessor.

System Requirements

- The program is being developed mainly for the Windows environment. It is actively tested on Windows 10, Windows 7 and Windows XP (in Virtual Machine). GUI is a 32-bit application but 64-bit windows based simulation engine is a part of standard distribution. 32- and 64-bit ports of simulation engine for Linux are tested and available on request, GUI runs in Virtualbox and/ or under WINE.

- The system requirements will depend on the type of application. For two-dimensional self-standing simulations, the requirements are very low. For realistic 3D models a few gigabytes of RAM are needed as the program uses direct solver. To use the graphical user interface the computer must support OpenGL.

<http://sites.udel.edu/lims/>



Simulation of CRTM filling of an automotive pillar, possible because of the scripting control.

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