Generalized Anisotropic/Isotropic Porous Media Flows in LS-DYNA

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1 Abstract

Among the current needs of large industries and engineering companies is the ability to perform numerical simulations of complex processes that require the coupling of multiple fields, each representing a different physical model and/or phenomena. Processes involving fluid flows through porous media matrices are present in a wide range of these kind of problems.
In the ground vehicles industry, understanding aerodynamics phenomena allows us to optimize the operation of a wide spectrum of road vehicles, that ranges from road passenger transport (cars, buses, trains) to road commercial transport (trucks and trains). Road vehicle aerodynamics is a complex topic due to the interaction between the air flow and the ground and some parts (that play an important role in drag and lift development) could be treated as a porous media (e.g. the radiator, the condenser, air filters, etc).
In recent years industries like aerospace and those related to oil production have increased their trustfulness on numerical models and codes for the design, research, production and verification of highly critical parts and production processes. Most of these industries have adopted manufacturing procedures involving composites materials in liquid state, like the Liquid Composite Molding (LCM) and the High Pressure Resin Transfer Molding (HPRTM) methods, where a Newtonian (or Non-Newtonian) fluid flows through highly anisotropic matrices filling an initially empty container.
In this article the numerical modeling of the flow through general anisotropic porous media using LS-DYNA is introduced. A generalization of the Navier-Stokes equations that will allow the definition of sub-domains with different permeability/porosity was developed. The SUPG|OSS stabilizing Finite Element Method for the spatial approximation and the second-order Fractional Step Method for the time integration were adopted. Also, the paper will provide some examples showing the use of LS-DYNA in a wide range of low problem. Details about how the users' interface looks like will be given at the conference talk (it also can be found in the LS-DYNA users manual).

Keywords: computational fluid dynamics, anisotropic/isotropic porous media flow, multi-physics, coupled problems, free surface flows.

2 Introduction

Besides of fuel consumption, aerodynamics is directly related to vehicle stability: the flow-vehicle interaction impacts on the straight line stability (road-holding), dynamic passive steering and the response to crosswind. Furthermore, there are other issues where the aerodynamics plays an important role: the accumulation of droplets of rain water on windows and outside mirrors, the accumulation of dirt in headlights, wind noise, etc. In summary, aerodynamics has a significant impact on the design of a vehicle and requires a detailed analysis of the ow around it, including unsteady and turbulent flow phenomena. A road vehicle has also aerodynamic properties that are specific to this kind of vehicles. Due to its geometry, it can be considered a bluff body, which means that drag is mainly due to the pressure acting on it. Skin friction, caused by viscous shear forces on the surface of the vehicle, has only a small contribution to the drag. Flow separation occurs in the back of the body, creating large re-circulation regions in the near wake, resulting in a lower pressure on the back surfaces. Furthermore, the new features added to the incompressible fluid solver of LS-DYNA allow the modeling of the aerodynamics of ground vehicles with a complete description of what is happening inside the engine compartment.

The natural generalization of the Navier-Stokes model for the incompressible fluid dynamics is the key point of the multi-physics coupling developed in LS-DYNA. This approach allows to user to model problems of 3D fluid infiltration through a porous media matrix with a moving free surface, like the so called Resin Transfer Molding process (RSM). Infiltration process basically depends on the local porosity, the local orientation of the fibers and on their packing density. In LS-DYNA, such a problem can be modeled with the ICFD+Multi-physics solver using an implicit second-order Fractional-Step time integration. Basically, the porous media solver implements the Ergun Correlation and the Darcy-Forchheimer force models in both the anisotropic and the isotropic forms. The fluid constitutive relation, describing the fluid stresses as function of the fluid velocity field could play an important role in RSM and LCM processes. For this purposes, LS-DYNA implements not only the classical Newtonian model but also a non-Newtonian model based on the power law. The fluid temperature field transport is also coupled to the structural thermal solver through the Conjugate Heat procedure described in previous articles.

With the multi-physics capabilities of LS-DYNA engineers can couple CFD analysis with a thermal and/or structural solver in order to solve more complex and realistic problems in industry and general engineering. In particular, the generalization of the Navier-Stokes equations allows the definition of sub-domains with different permeability/porosity. The SUPG|OSS stabilizing Finite Element Method for the spatial approximation and the second-order Fractional Step Method for the time integration were adopted.

3 The General Incompressible CFD solver in LS-DYNA.

In recent years LSTC has devoted big efforts in the development of a CFD solver for incompressible flows. The solver is specifically designed to tackle coupled problems where low Mach numbers (M<0.3) are involved and a scalable parallel solution is needed. Some features of the solver include:

1. Implicit solver to allow larger time steps,
2. Optimal MPP scalability,
3. Automatic mesh generation including boundary layer mesh,
4. Weak/Strong Fluid/Structure Interaction capabilities,
5. Turbulence models for RANS/LES, and turbulent inlet boundary conditions,
6. Generalized flow through porous media,
7. Free surface flows,
8. Coupled to the structural and thermal solvers.

Extensive validation has been performed to test the accuracy and robustness of the solver. The tests are documented and available thourgh our website.

4 Generalized Anisotropic/Isotropic Navier-Stokes flows through Porous Media.

4.1 General Model

A generalization of the Navier Stokes equations (see referece [1]) that will allow the definition of sub-domains with different permeability/porosity by means of the ***ICFD_PART** and ***ICFD_PART_VOL** keywords was implemented. Material parameters are introduced via ***ICFD_MAT** keyword (4th CARD, see user's manual). When using coupled Navier-Stokes/Porous Media a ***MESH_INTERF** needs to be defined in the interface between porous and non-porous regions. We use an OSS|SUPG stabilized Finite Element Method for the spatial approximation and an implicit second order Fractional-Step scheme for the time integration.

Basically, four different models where implemented so far:

i) the isotropic Ergun correlation,

ii) the Darcy-Forchheimer force model,

iii) a model for the definition of porous parameters using a pressure-velocity curve obtained from experiments, and

iv) a general Anistropic Darcy-Forchheimer model.

4.2 Validation of the model implementation.

The flow of a Newtonian fluid through a rectangular channel with a thick porous layer is considered interchanging mass and momentum through a common interface. This problem was extensively studied by Vafai et.al (see references [2] and [3]) and is a classical benchmark for 2D/3D NS/Porous flow coupling. The froblem definition is shown in Figure 1 (from Reference [3]). 2D LS-DYNA FEM results for the velocity field are compared to a theoretical solution in Figures 2 and 3.

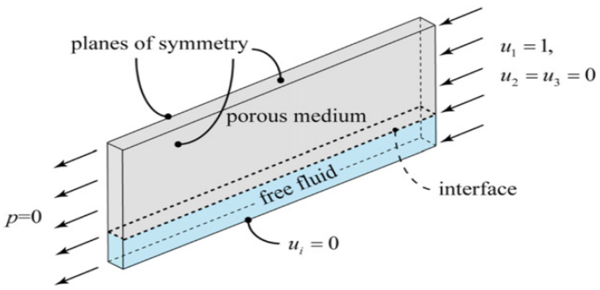

Figure 1: Domain an problem definition ([3]).

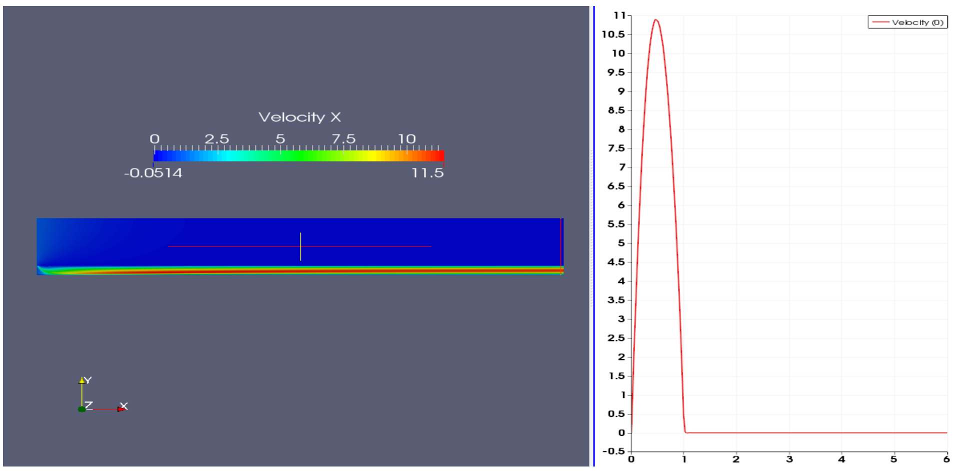

Figure 2: absolute value of the velocity field using FEM.

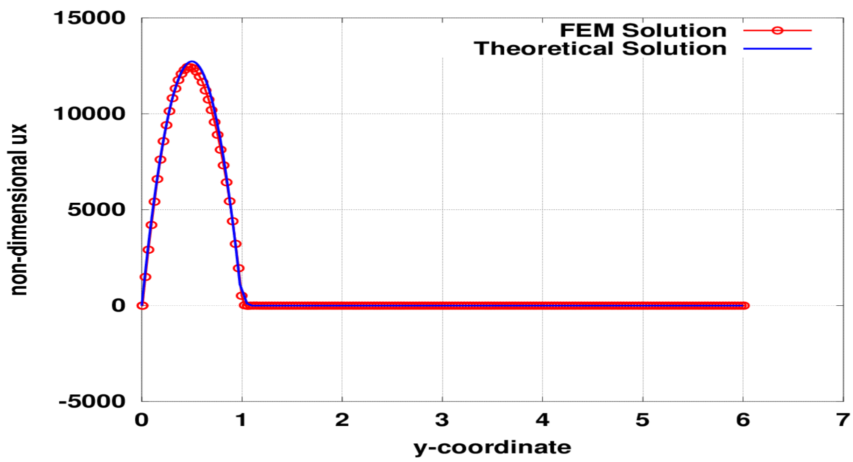

Figure 3: FEM vs. Theoretical results.

3D LS-DYNA results are shown in Figures 4 and 5.

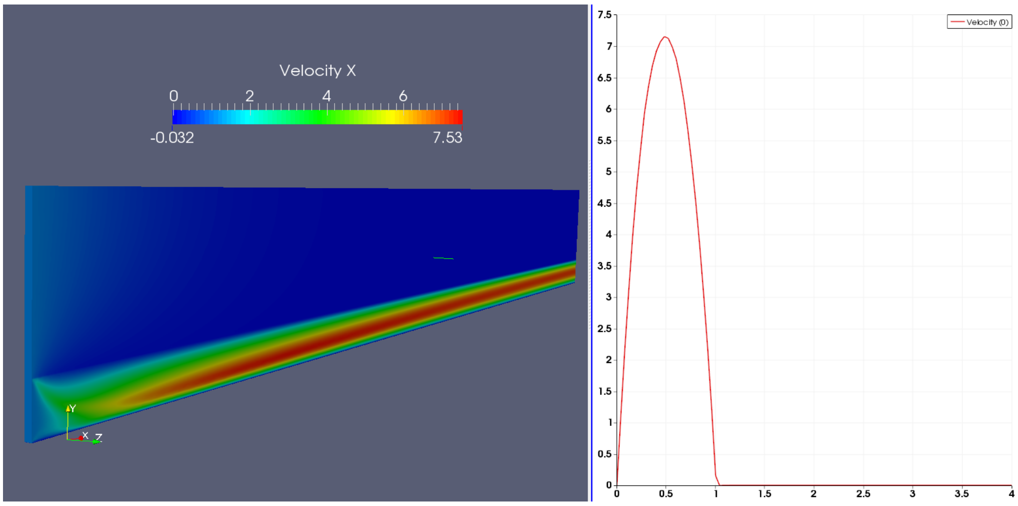

Figure 4: 3D FEM solution.

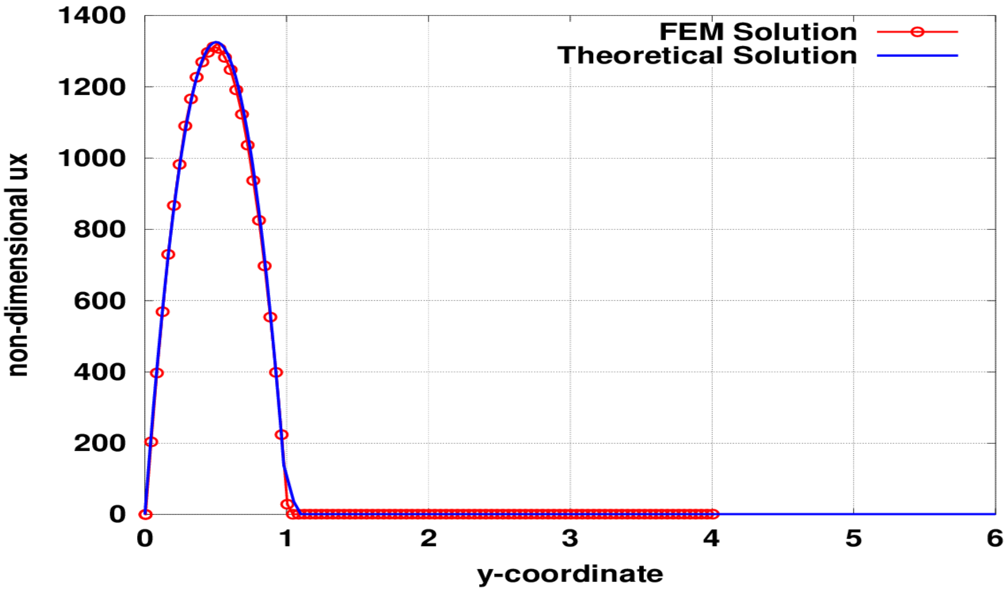

Figure 5: 3D results: FEM vs Theoretical.

4.3 Resin Transfer Molding in an Anisotropic Multi-Porous Domain.

The following example is a RTM problem where a Newtonian fluid is injected into a mold at high speed. The porous domains consists in two highly anisotropic regions embedded in an isotropic matrix (see Figure 6.). In Figure 7 the sequence of solutions, for the velocity field and the position of the free surface is shown for several time steps.

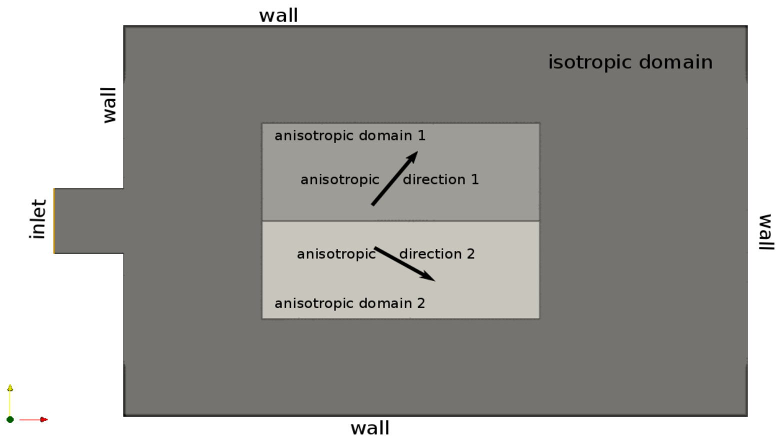

Figure 6: Domain and problem definition.

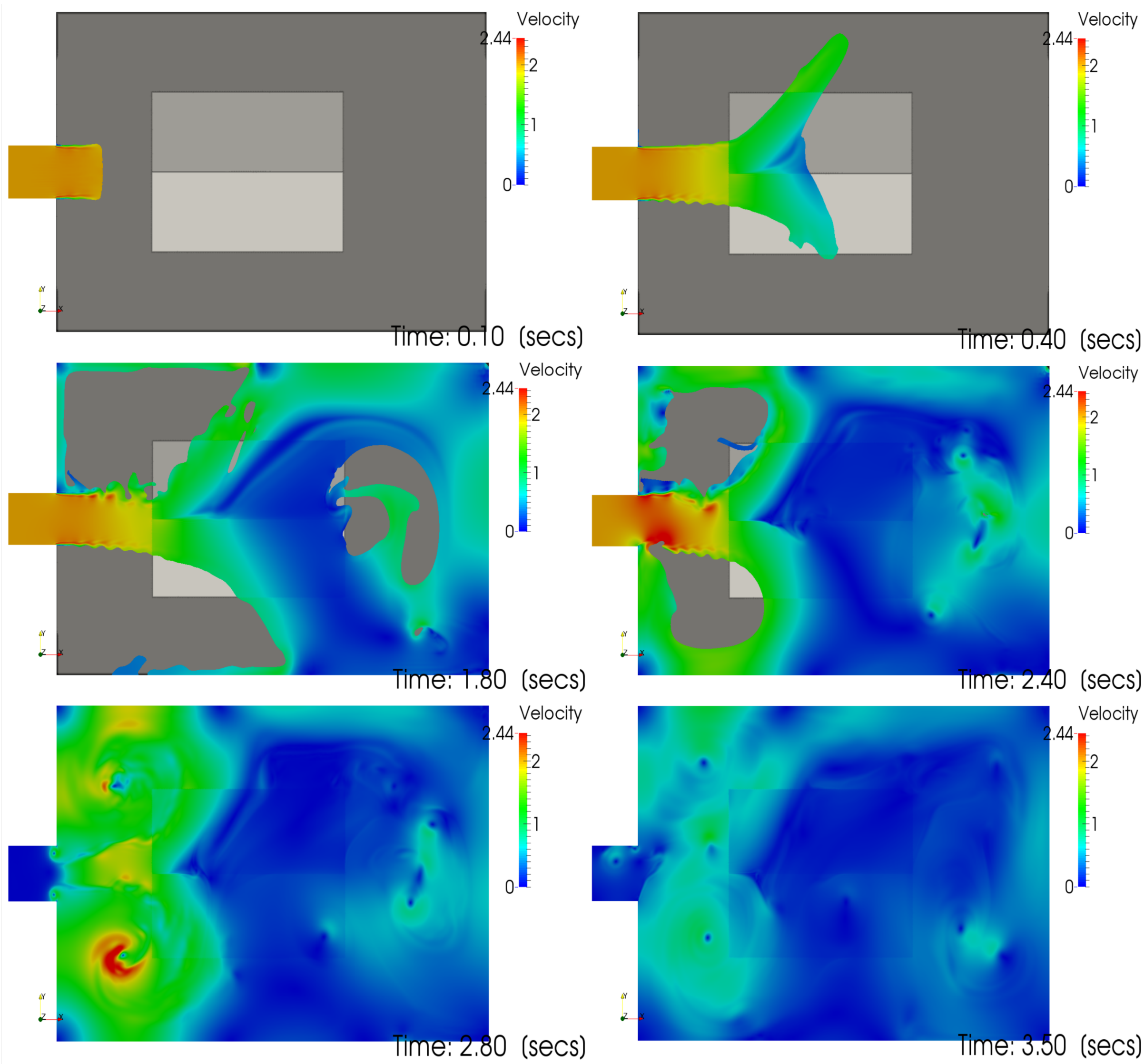

Figure 7: RTM sequence in multi-porous domain.

4.4 Ground vehicle aerodynamics and thermal coupling.

A car aerodynamics problem with thermal transport was solved using a model which was provided by GMC for an aerodynamic benchmark. The model includes the engine compartment, the radiator (treated as a porous media), exhaust, suspension, wheels, grill and mirrors. The model and mesh is shown in Figure 8. The aerodynamics analysis was performed with a thermal analysis to predict the fluid temperature around the engine block and exhaust tubes. The results are shown in Figures 9 through 12. Generally speaking, the heat equation for the fluid can also be coupled to the heat equation of the structural problems to perform Conjugate Heat Transfer analysis allowing a complete and coupled analysis in a full non-linear analysis.

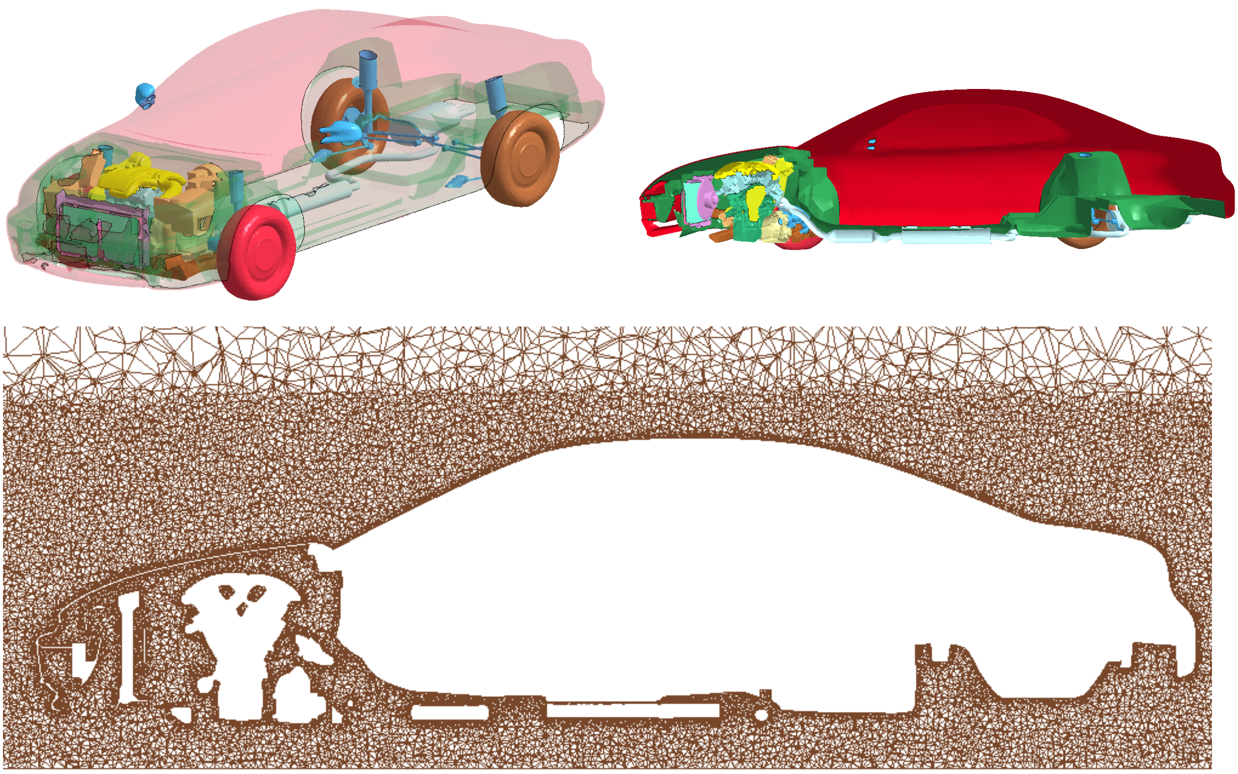

Figure 8: Geometry and volume mesh of a GM Pontiac model.

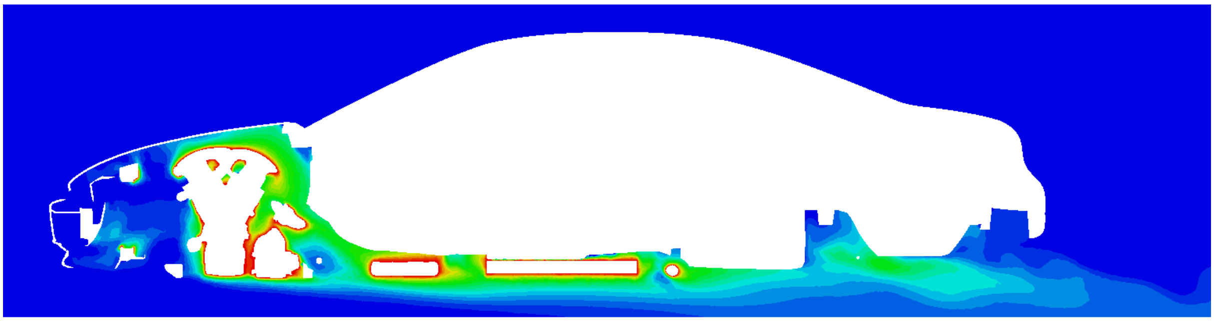

Figure 9: fluid temperature in a cutplane at the symmetry plane.

Predicted aerodynamic drag is shown in Figures 10 and 11 for the cases including and not including the radiator in the engine compartment.

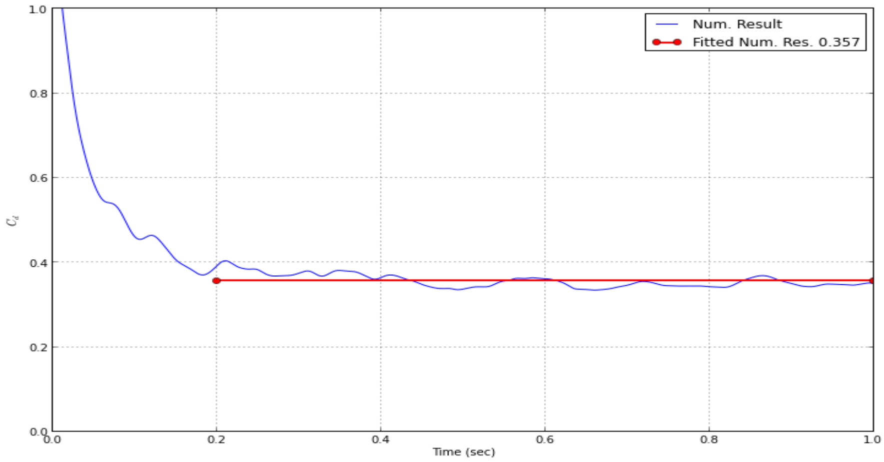

Figure 10: Drag force without the radiator.

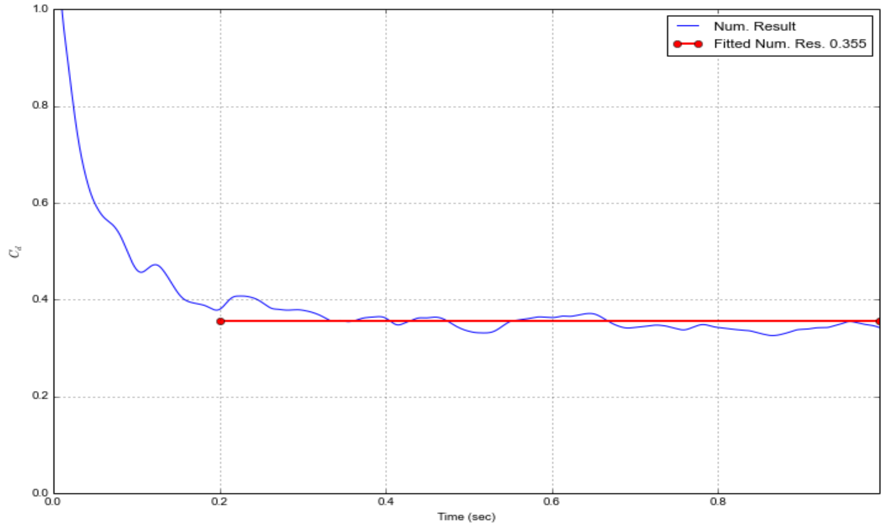

Figure 11: Drag force including the porous model for the radiator.

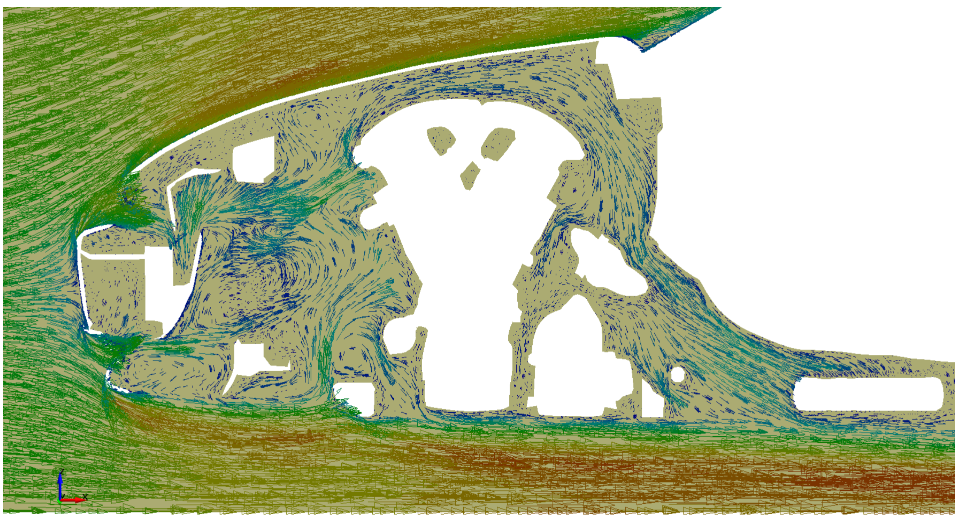

Figure 12: Flow field inside the engine compartment and the radiator.

5 Summary

This paper introduced some of the new features that LS-DYNA offers in the area of multi-physics, including general CFD flows, flows through anisotropic or isotropic multi-porous domains, Free-Surface, and thermal analysis. Academic benchmarks and industry/engineering test problems were presented. Details on the users' interface will be given at the conference talk.

References

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