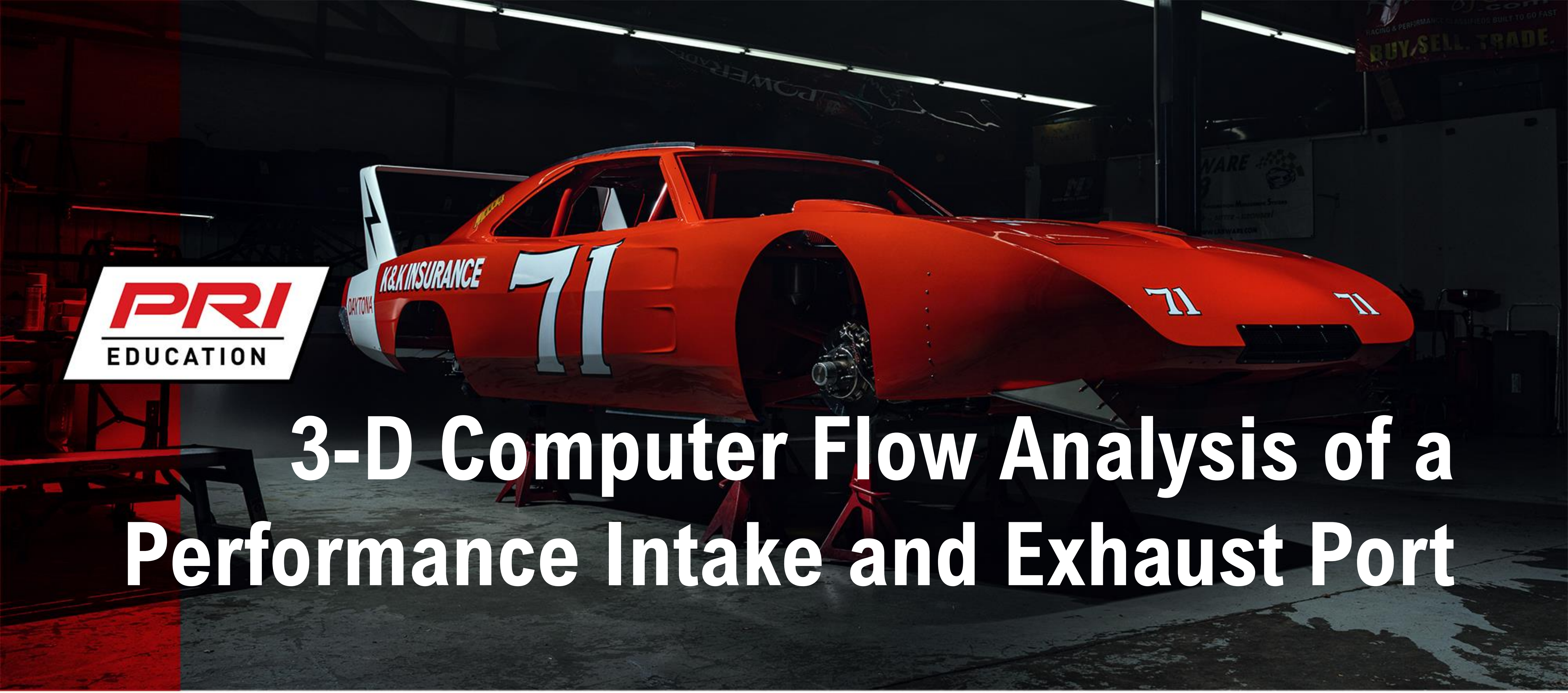


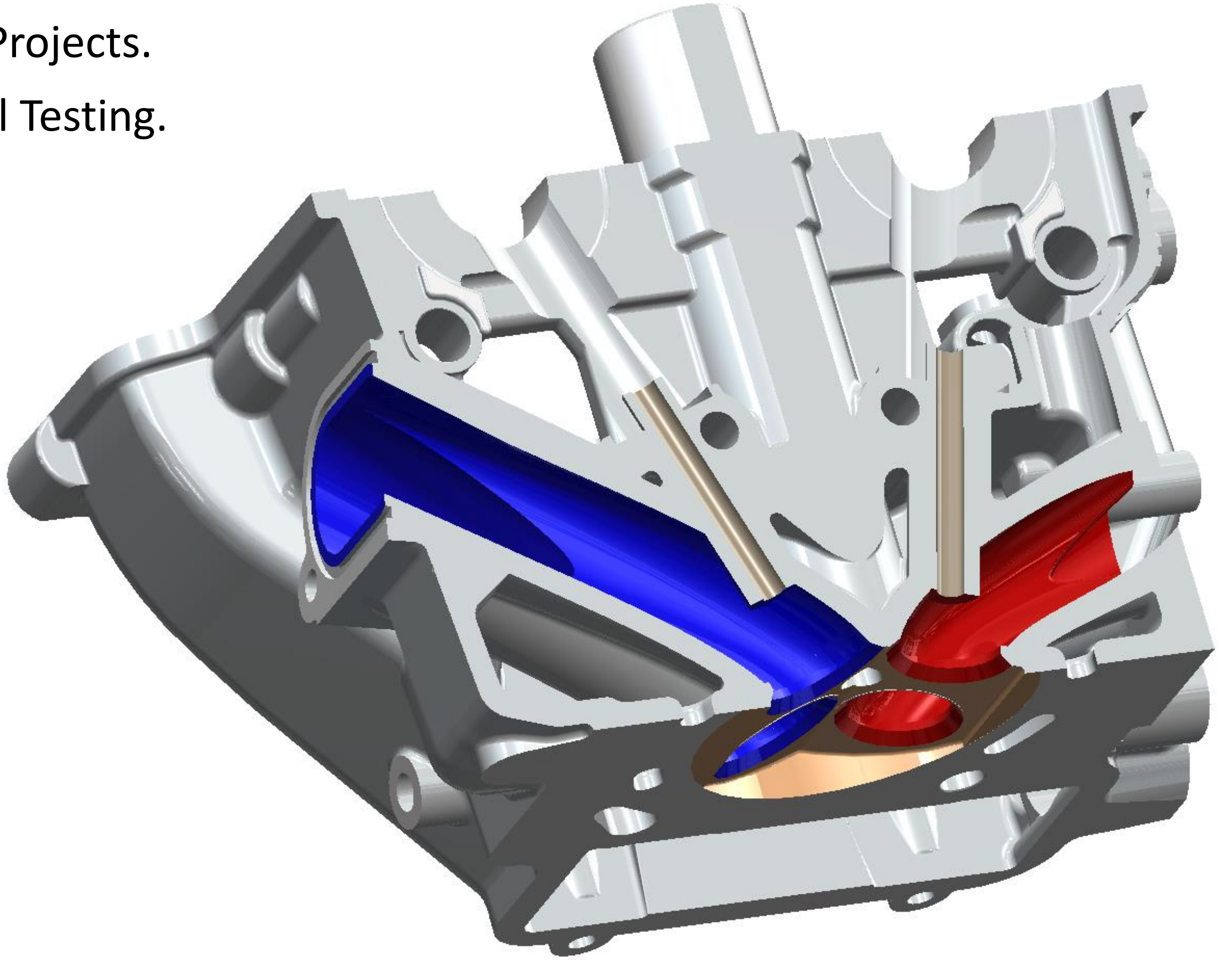
PRI EDUCATION

3-D Computer Flow Analysis of a Performance Intake and Exhaust Port

Dan Agnew
Principal Engineer, EngSim Corporation

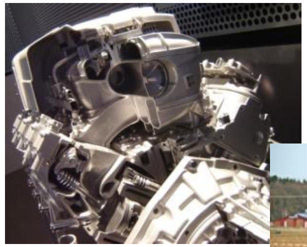
Outline

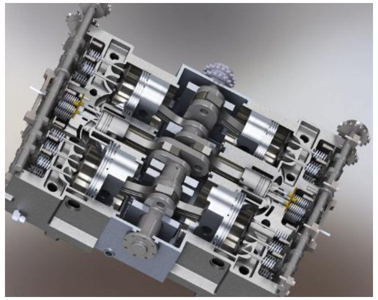
1. Background
   a. About EngSim Corporation and our Typical Types of Projects.
   b. Purpose of this Project and Comparison with Physical Testing.
   c. Typical Types of Computational Fluid Dynamics (CFD) Projects at EngSim.
   d. CFD Software.
   e. Use of 1-D Engine Simulation to Support Port Flow Work Questions.
2. Port Flow Project
   a. Computer Aided Design (CAD) Model.
   b. CFD Model.
   c. Setup and Cases Studied.
   d. Results.
3. Summary
   a. Logical Next Steps.
   b. Outlook for Future.
   c. References and Contact Info.



Background – About EngSim Corporation

1. EngSim is an engineering service company specializing in powertrain and vehicle computer simulation.
   a. Typical Projects
      i. IC Engine
      ii. Battery Electric Powertrain
      iii. Valvetrain
      iv. Cooling, Lube/Oil
      v. Vehicle Systems – Traditional Automotive or Racing, HD Truck, Locomotive, Battery/Hybrid Electric Vehicle



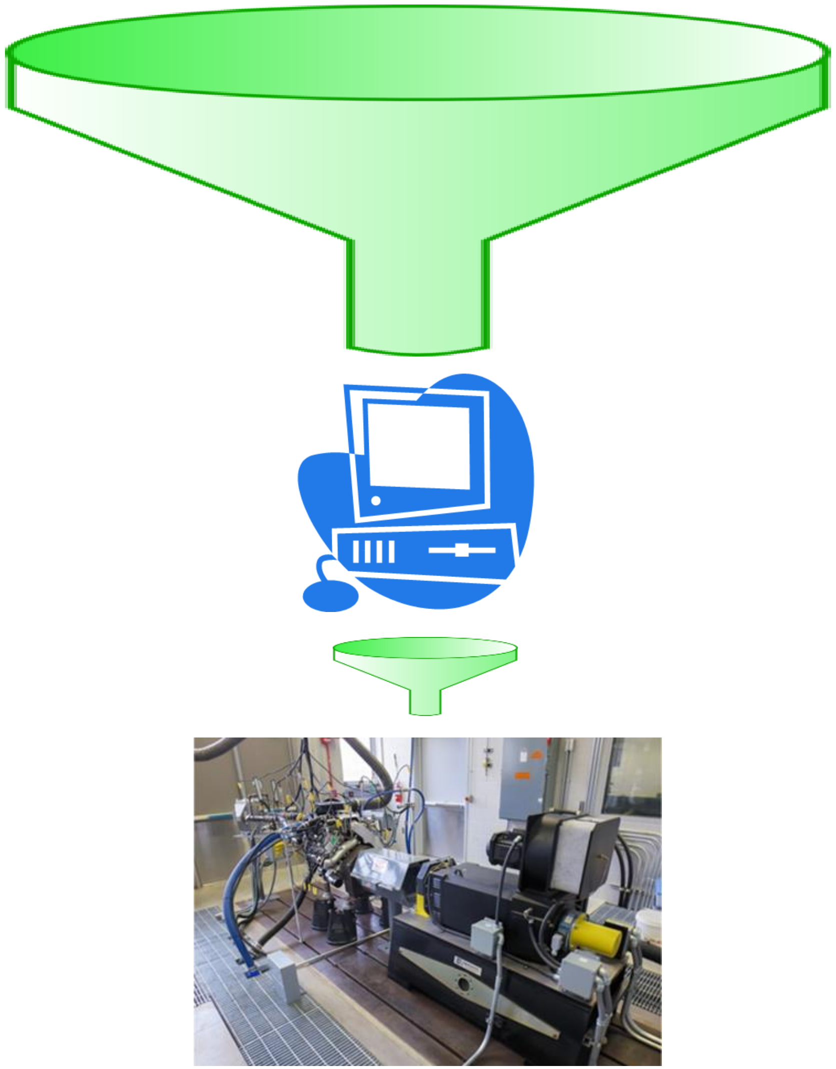




   b. For many clients, EngSim is their “virtual” engineering department for “virtual” engineering/testing.

Background - Purpose of the Project

PRI EDUCATION

1. Use this project to demonstrate how CFD can support future testing prior to hardware.
    a. Early determination and understanding of flow capacity and in-cylinder mixture motion – filtering out the crazy ideas.
    b. Qualitative views of flow field to help understand what happens in the ports and in-cylinder to see problem areas.
    c. Support other forms of early simulation for power/torque estimations.
    d. Provide the basis for future advanced transient and combustion CAE.



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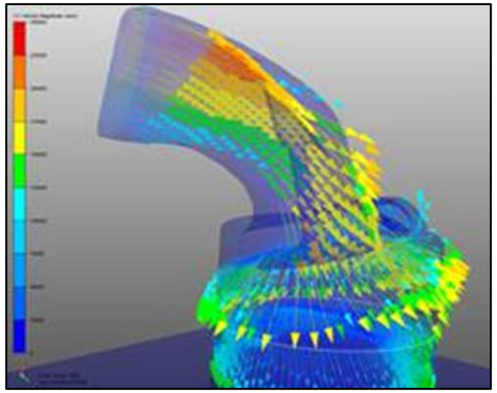
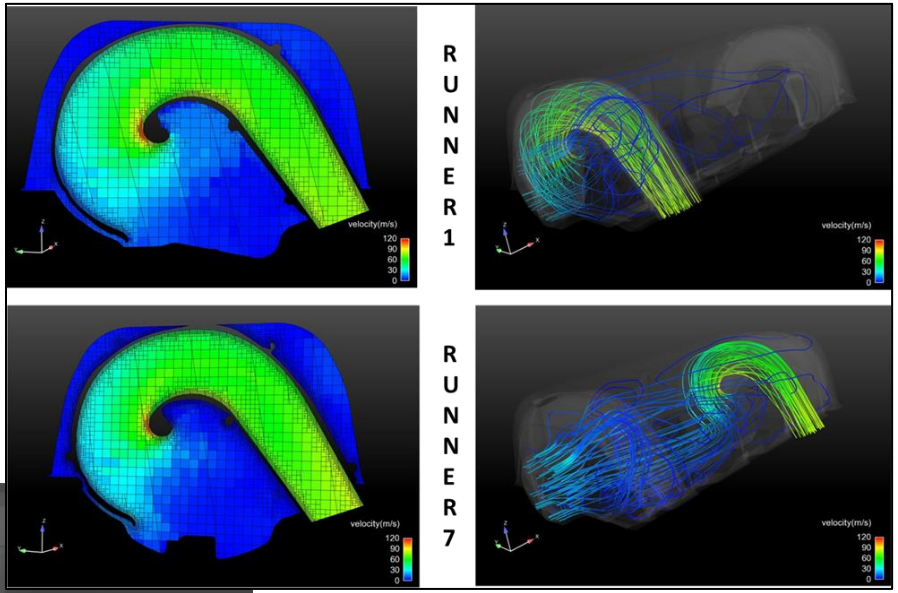
Background – Comparison with Physical Testing

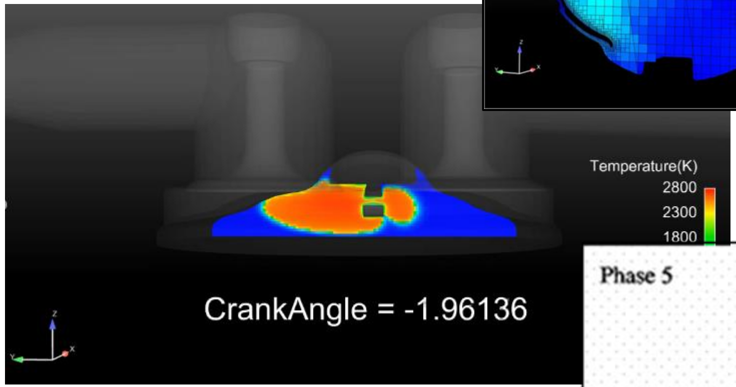
Attribute	Flowbench 	CFD 
Resources needed	Flowbench, fixtures, machining equipment, testing accessories, computer software or spreadsheet	Computer workstation, CFD software and license
Personnel	Experienced technician, machinist	Experienced CAD/CAE engineer
Test model	Test flowbox or head/manifold…etc	CAD model
Output	Flow capacity, overall swirl/tumble	Flow capacity, overall swirl/tumble, detailed and localized flow field speed and direction. Advanced combustion – transient flow, fuel/air/PCV/EGR mixing, flame propagation, burn rate.

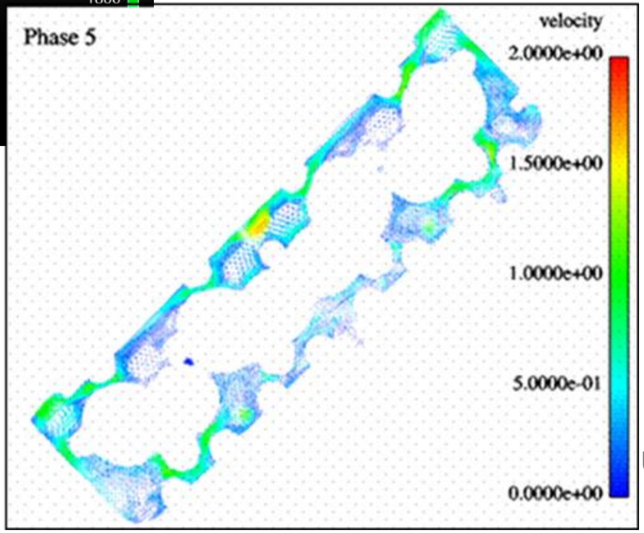
Background – Typical EngSim CFD Projects

1. Steady air flow
   a. Ports
   b. Manifolds
   c. Enclosures
2. Advanced cylinder head port flow
   a. Transient moving valves and pistons
   b. In-cylinder combustion
3. Exhaust
   a. Manifolds
   b. Diesel particulate filters
   c. EGR coolers
4. Head and block waterjacket flow
   a. Cold flow
   b. With heat transfer









Background - CFD Software

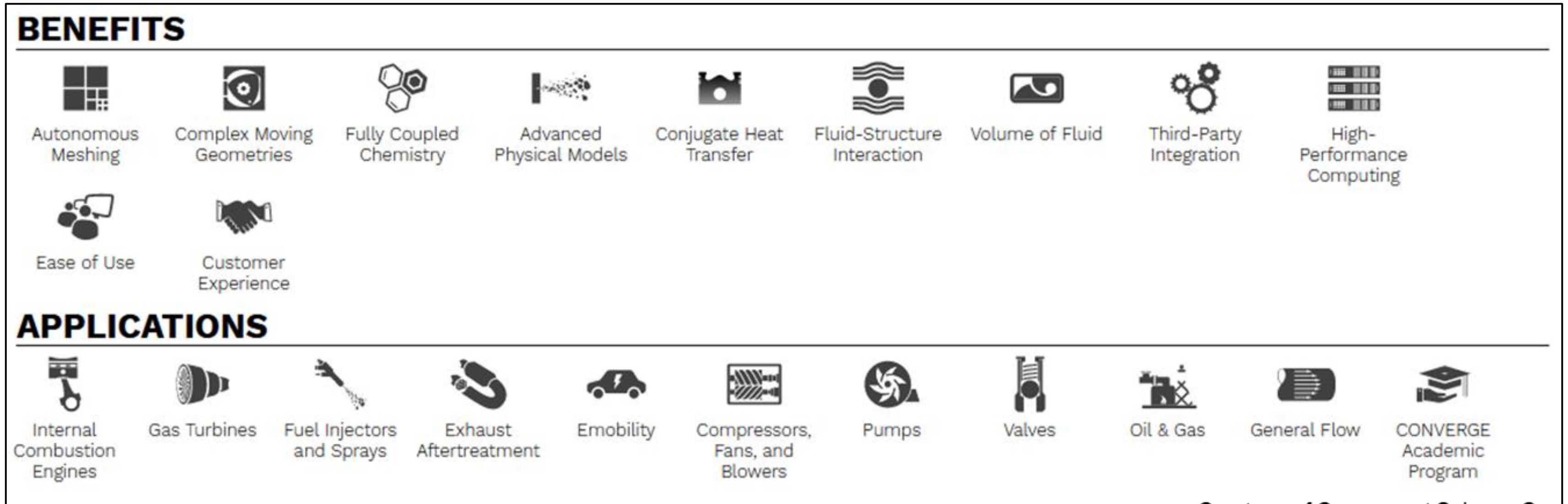
PRI EDUCATION

1. Many CFD software tool choices are available.
2. EngSim has been primarily using CONVERGE.
3. Secondarily, EngSim uses AVL FIRE in some specialized applications.
4. Both are industry leaders for predictive engine and in-cylinder flow and combustion with moving meshes.

CONVERGE CFD SOFTWARE

The Leader in Powertrain CFD

AVL FIRE™



Courtesy of Convergent Science Co.

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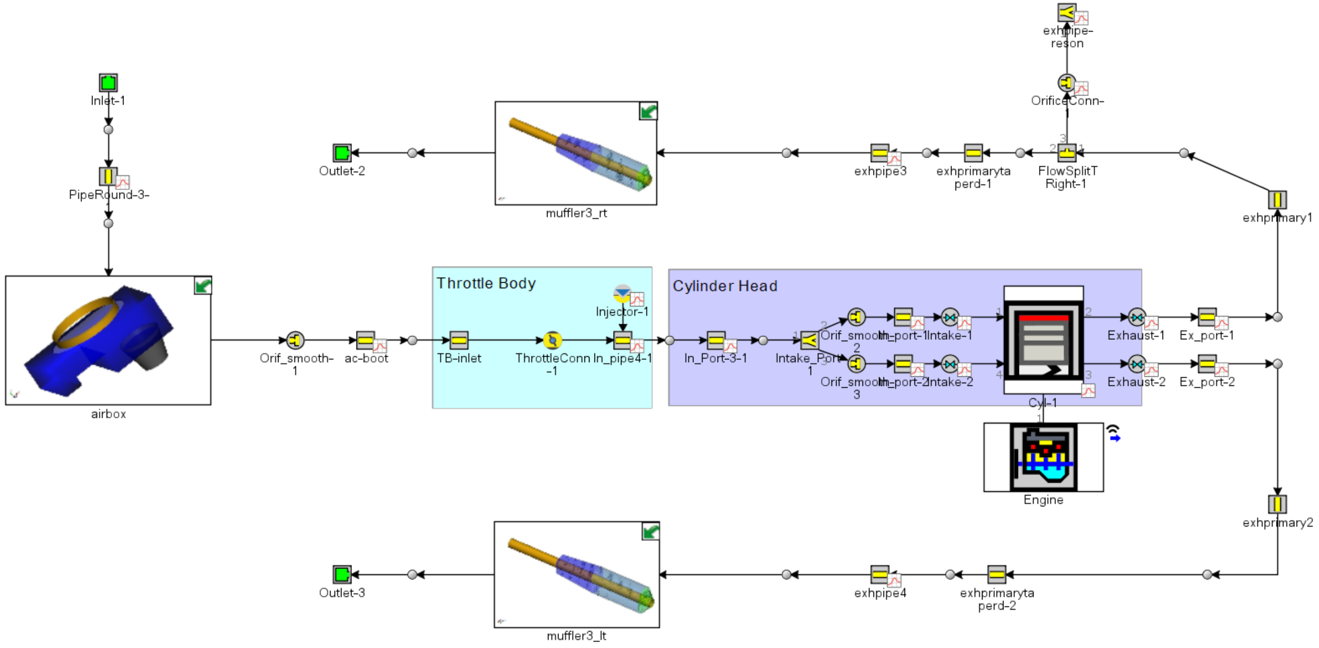
Background – 1-D Engine Simulation Support

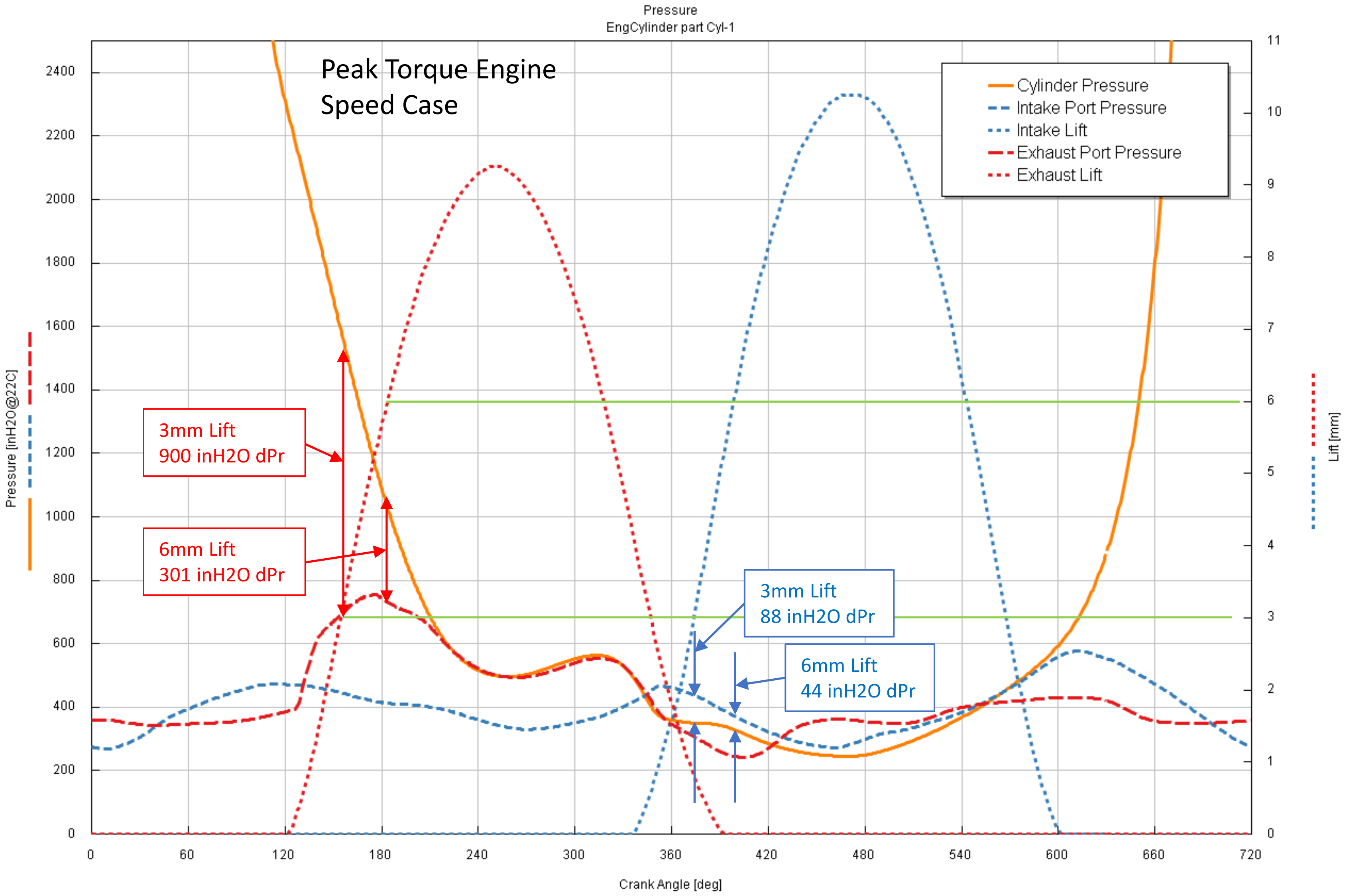
1. 1-D Engine Simulation Models can be used to answer several questions around port flow development ahead with CFD and of the hardware game…
   a. What pressure or vacuum should I use for my CFD model or flow bench testing?
   b. Where should I put my effort in port flow optimization – low, mid, or high lift?
   c. What's the effect of my changes on engine performance?



Background – 1-D Engine Simulation Support

What pressure or vacuum should I use for my CFD model or flow bench testing?

Typical flow bench test standards historically have been at 7 kPa (28 inH2O) for practical reasons, but as shown here could be considered quite unrealistic…



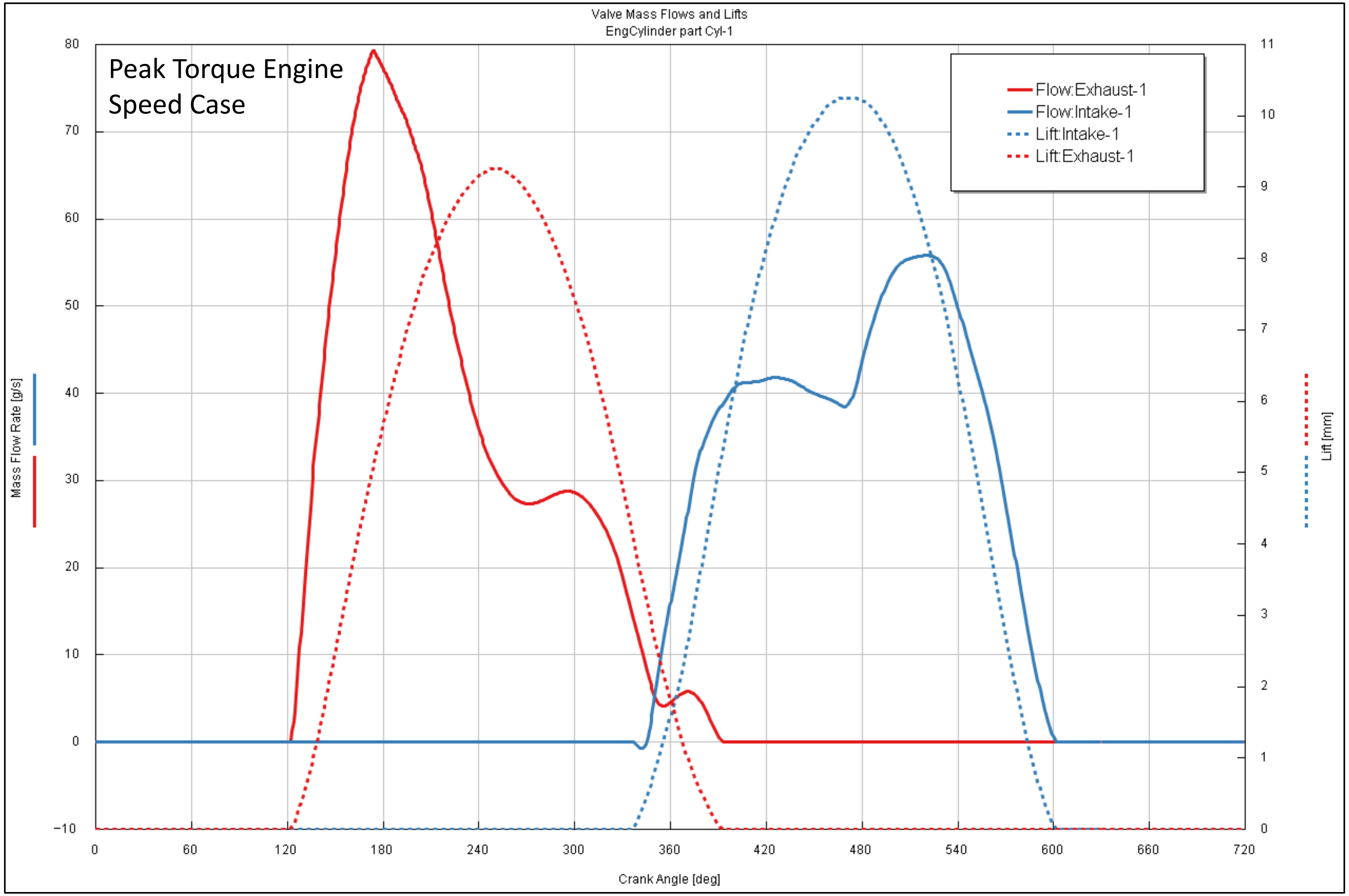
EngSim

Background – 1-D Engine Simulation Support

Where should I put my effort in port flow optimization – low, mid, or high lift?

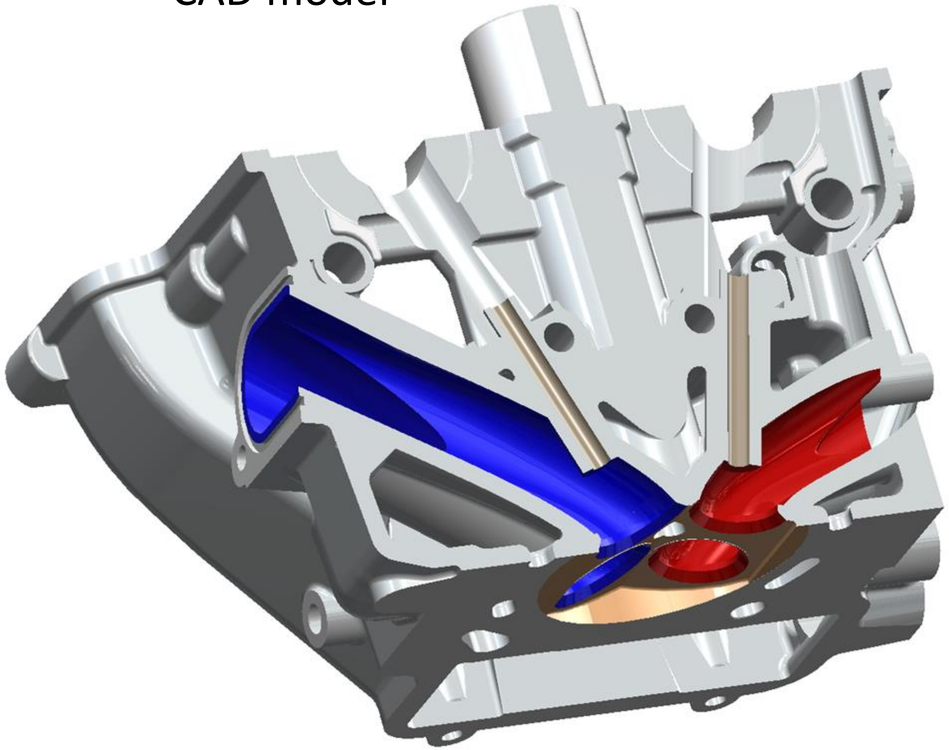
Look at the mass flow vs valve lift in your engine…

Low to mid-lift for the exhaust and mid to high-lift for intake seem to be the most important.

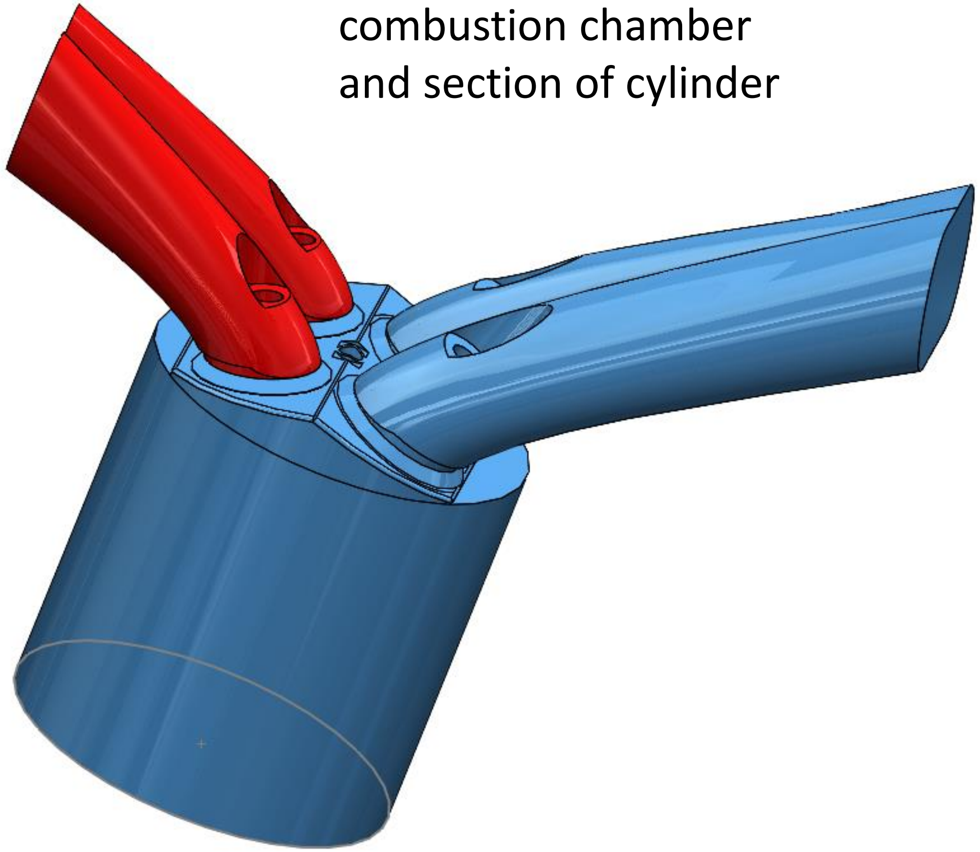


Port Flow Project – Computer Aided Design (CAD) Model

Cylinder head
CAD model

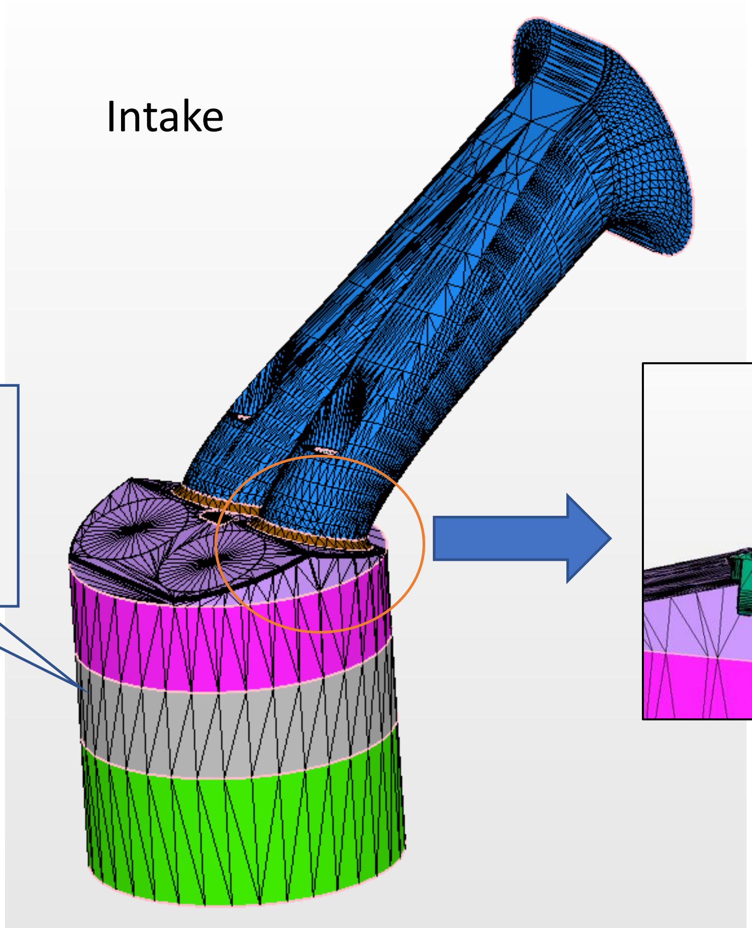


Solid air core of ports,
combustion chamber
and section of cylinder

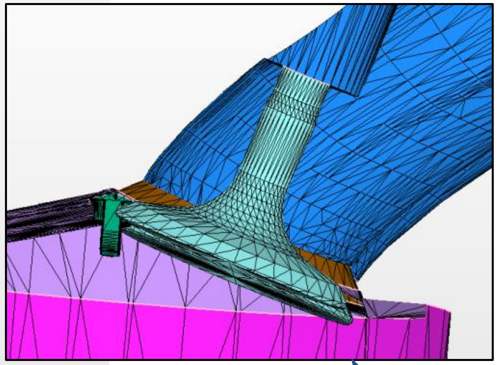


Port Flow Project – CFD Model

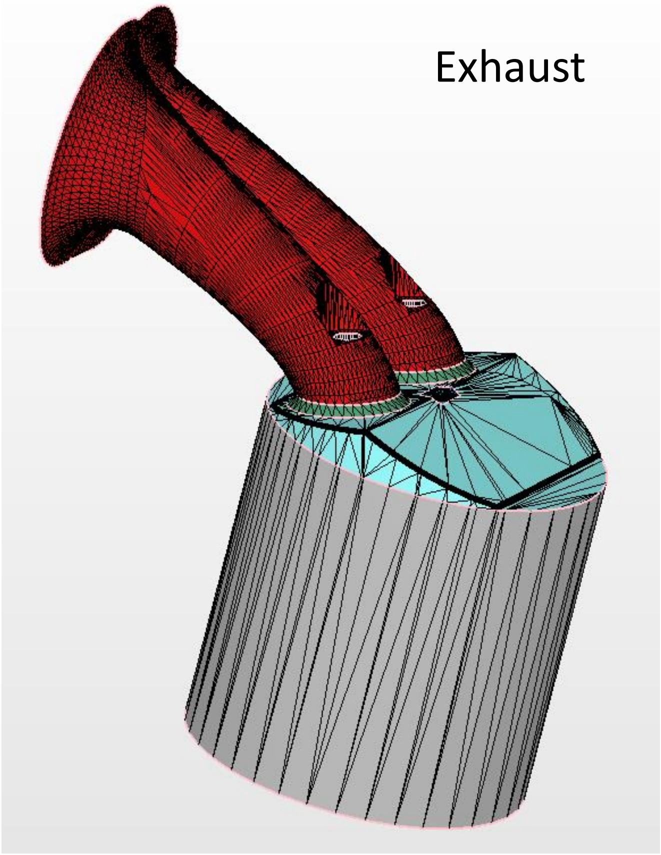
1. Intake and exhaust port models with combustion chamber, valves, and cylinder bore.
2. Intake model contains a middle section for assessment of in-cylinder mixture motion.



In-cylinder section for assessment of mixture motion



Section view of intake valve at 3mm



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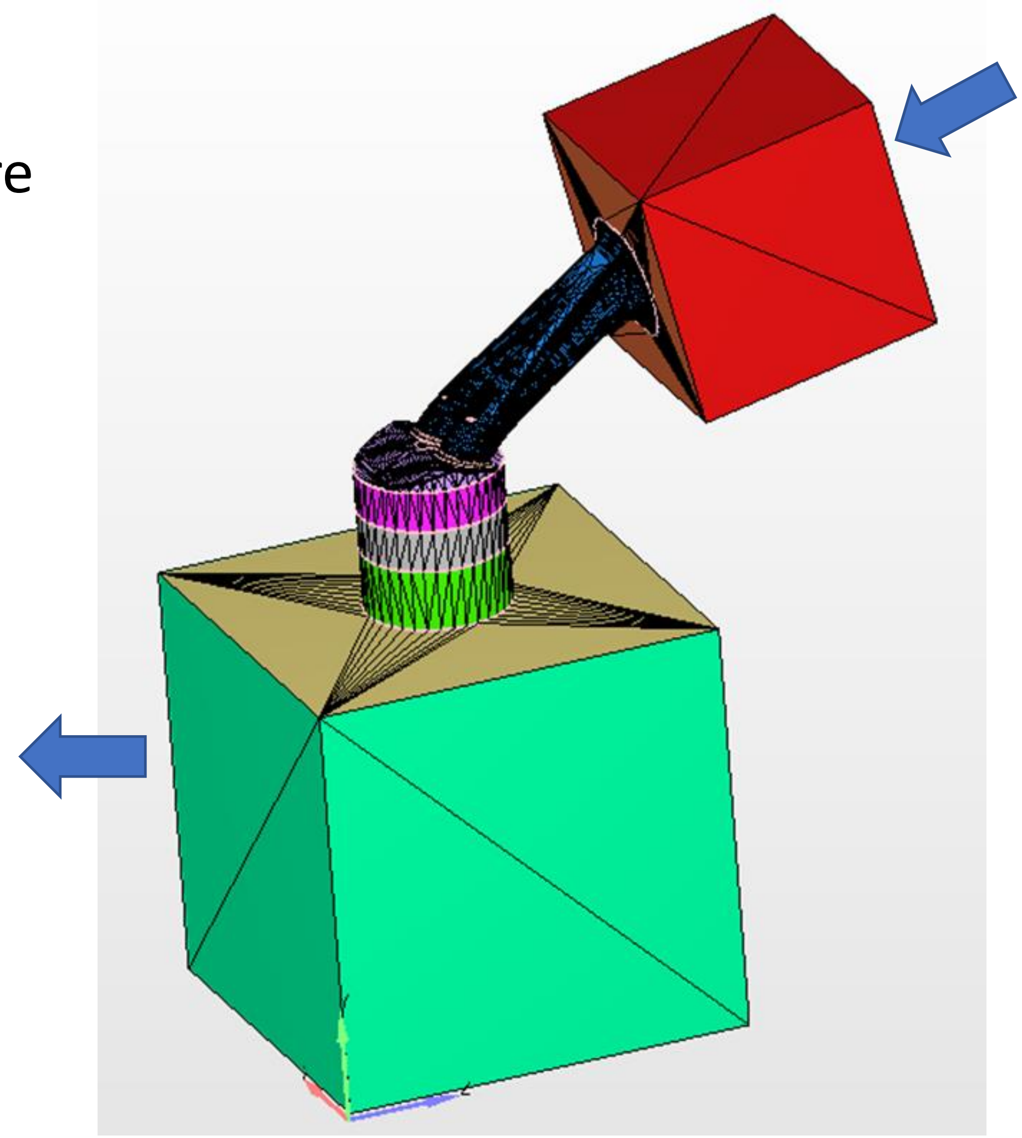
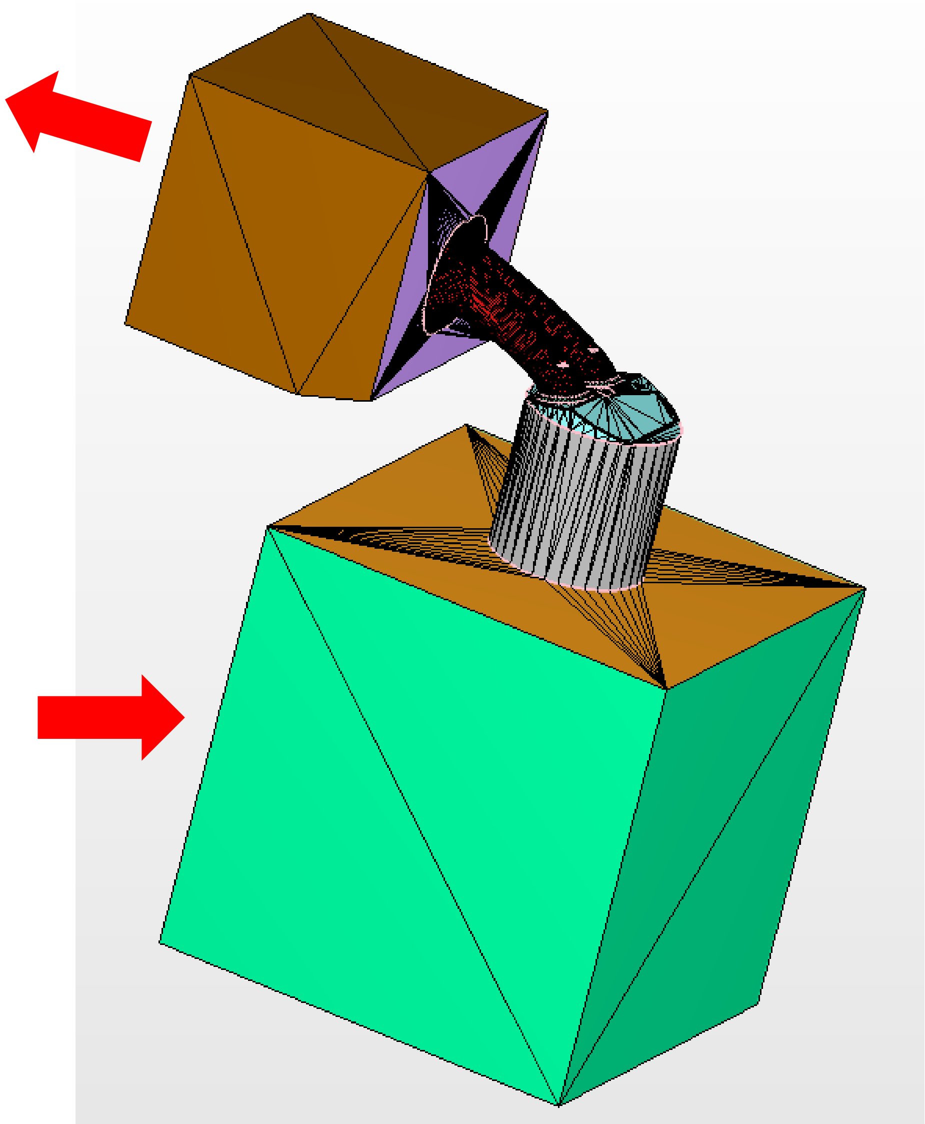
Port Flow Project – Setup and Cases Studied, Intake

1. Intake inlet plenum wall set to ambient pressure of 101.3 kPa and 294.3 K temperature (14.7 psia and 70F).
2. Outlet plenum wall set to 94.4 kPa which creates 7kPa (28 inH2O) of vacuum.
3. Cases
   a. Intake, both valves at 3mm
   b. Intake, both valves at 6mm
   c. Intake, one valve at 3mm and one at 6mm



EngSim

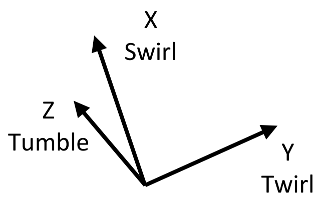
Port Flow Project – Setup and Cases Studied, Exhaust



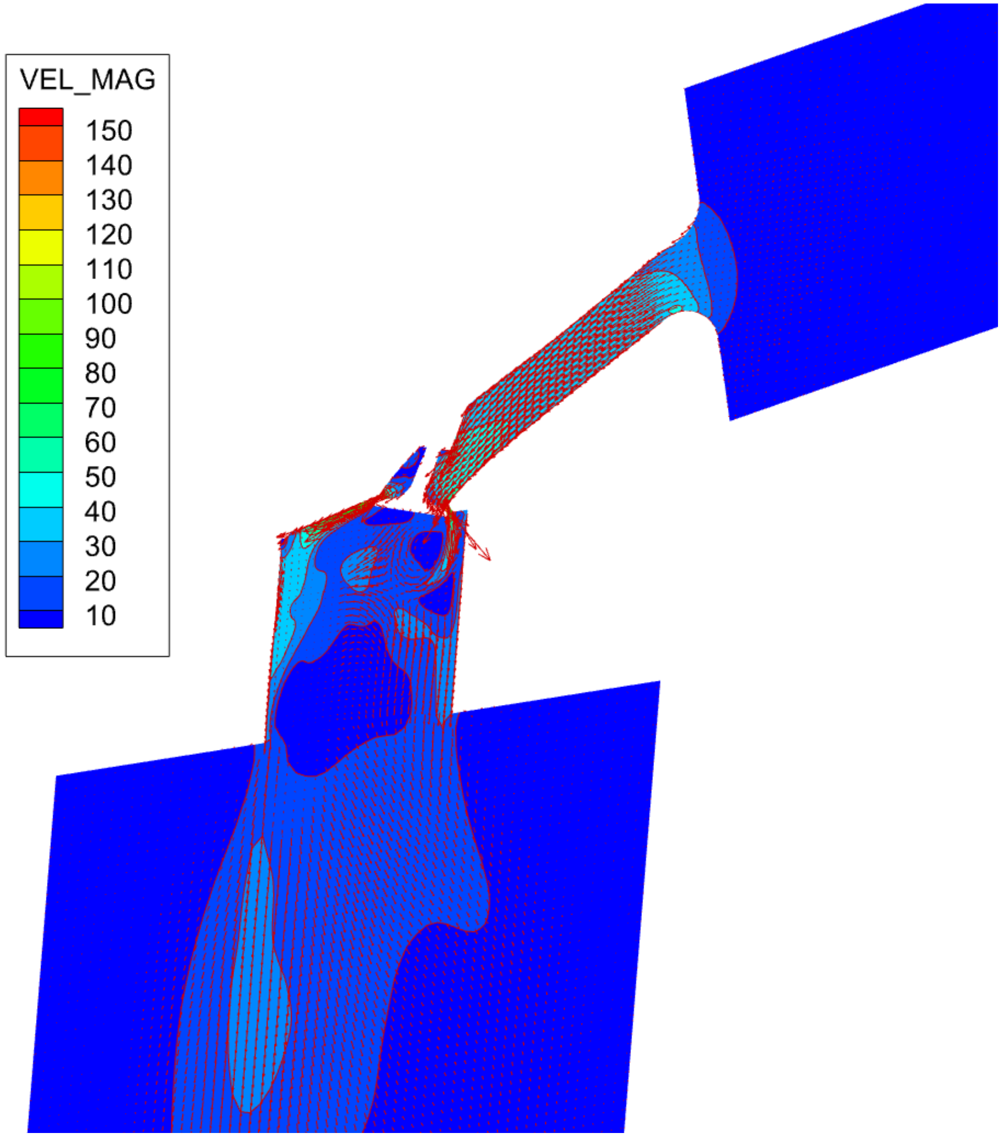
1. Exhaust inlet plenum wall set to 108.3 kPa and 294.3 K.
2. Outlet plenum set to 101.3 kPa which creates 7 kPa (28 inH2O) of pressure.
3. Cases
    a. Exhaust, both valves at 3mm
    b. Exhaust, both valves at 6mm

Results – General Flow and Mixture Motion

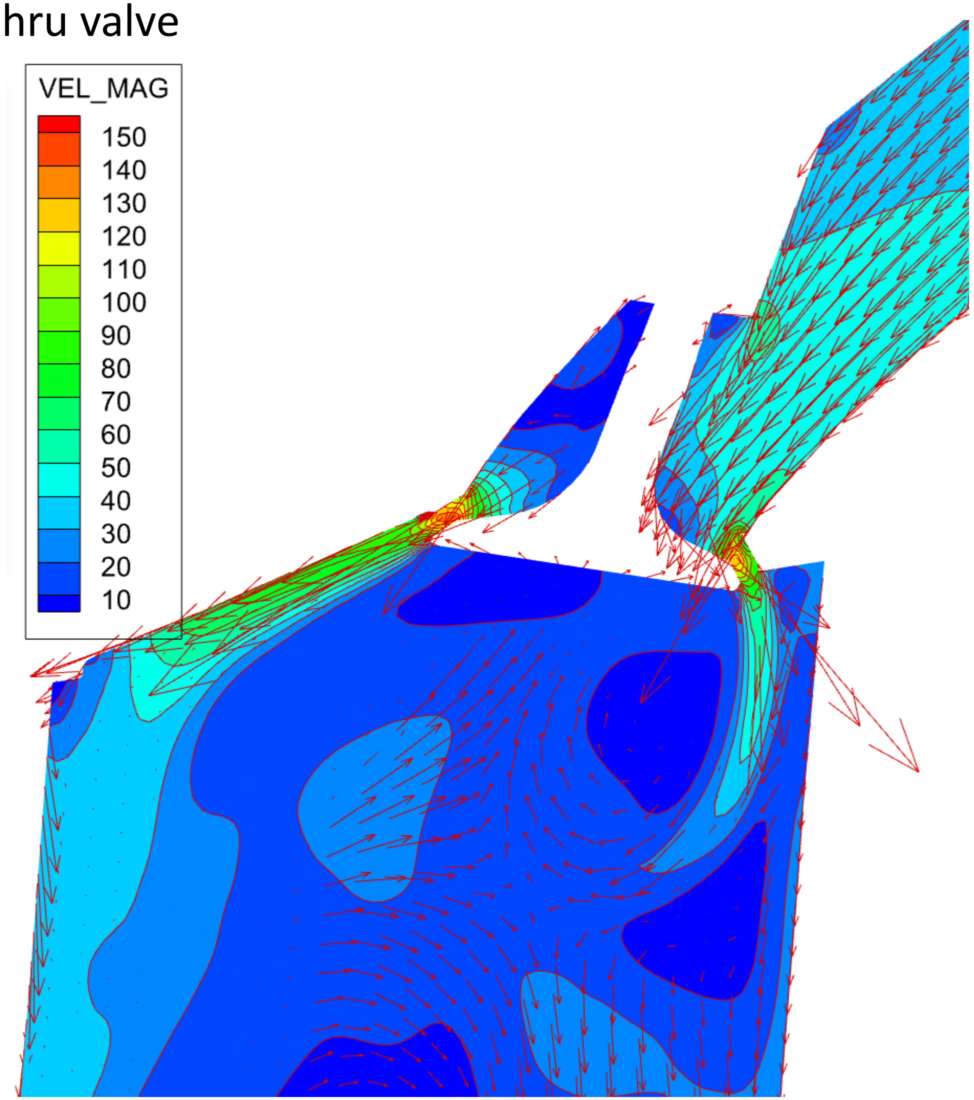
	Flow Capacity	Flow Capacity	Discharge Coefficient (1,2)	Angular Mom Flux - X	Angular Mom Flux - Y	Angular Mom Flux - Z
	g/s	SCFM	Valve Head OD	g-m^2/s^2	g-m^2/s^2	g-m^2/s^2
Intake – 3mm	55.1	104	0.264	-0.498	-0.454	7.59
Intake – 6mm	95.2	175	0.444	-0.862	-0.627	57.6
Intake – 3 and 6mm	75.6	139	0.353	-19.6	-25.1	39.9
Exhaust – 3mm	42.5	78.1	0.224	-	-	-
Exhaust – 6mm	63.6	117	0.335	-	-	-



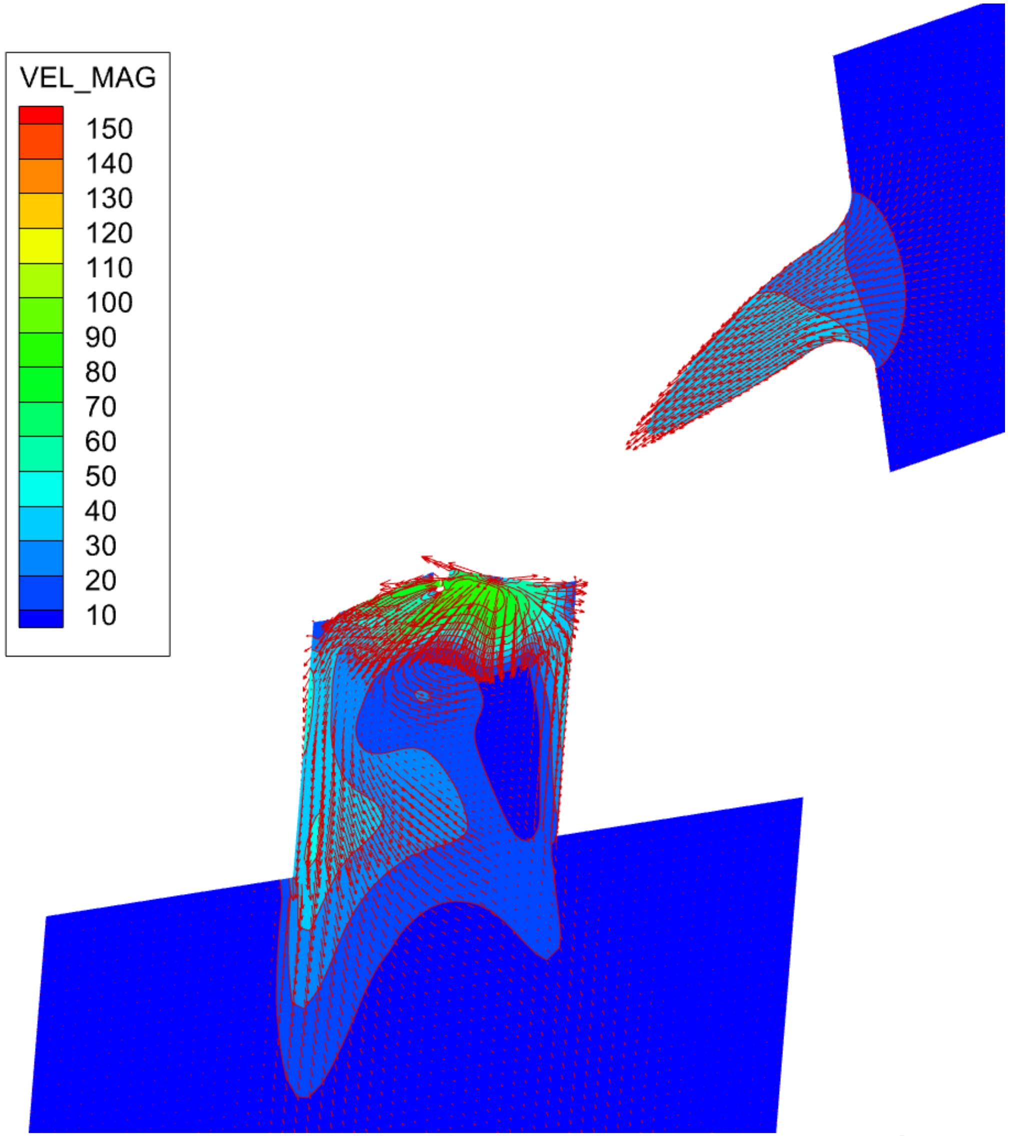
Results – Detailed Section Views – Intake at 3mm



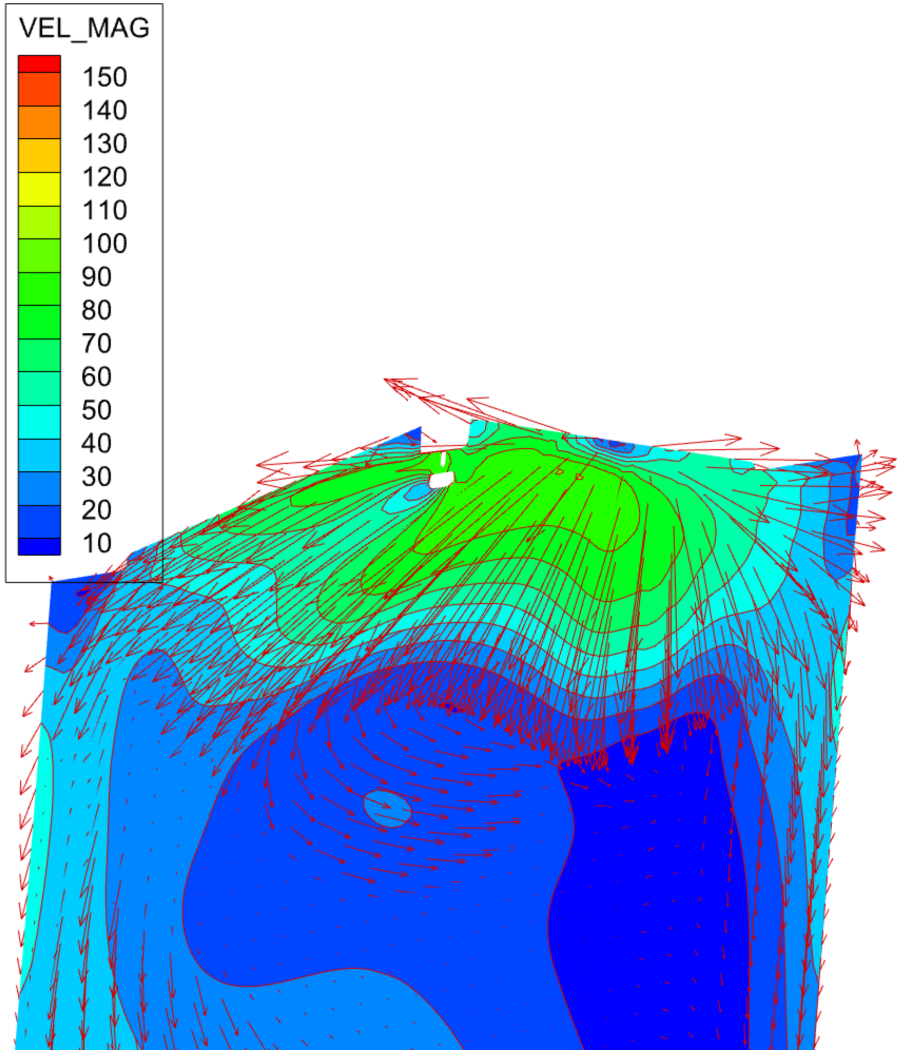
Section thru valve



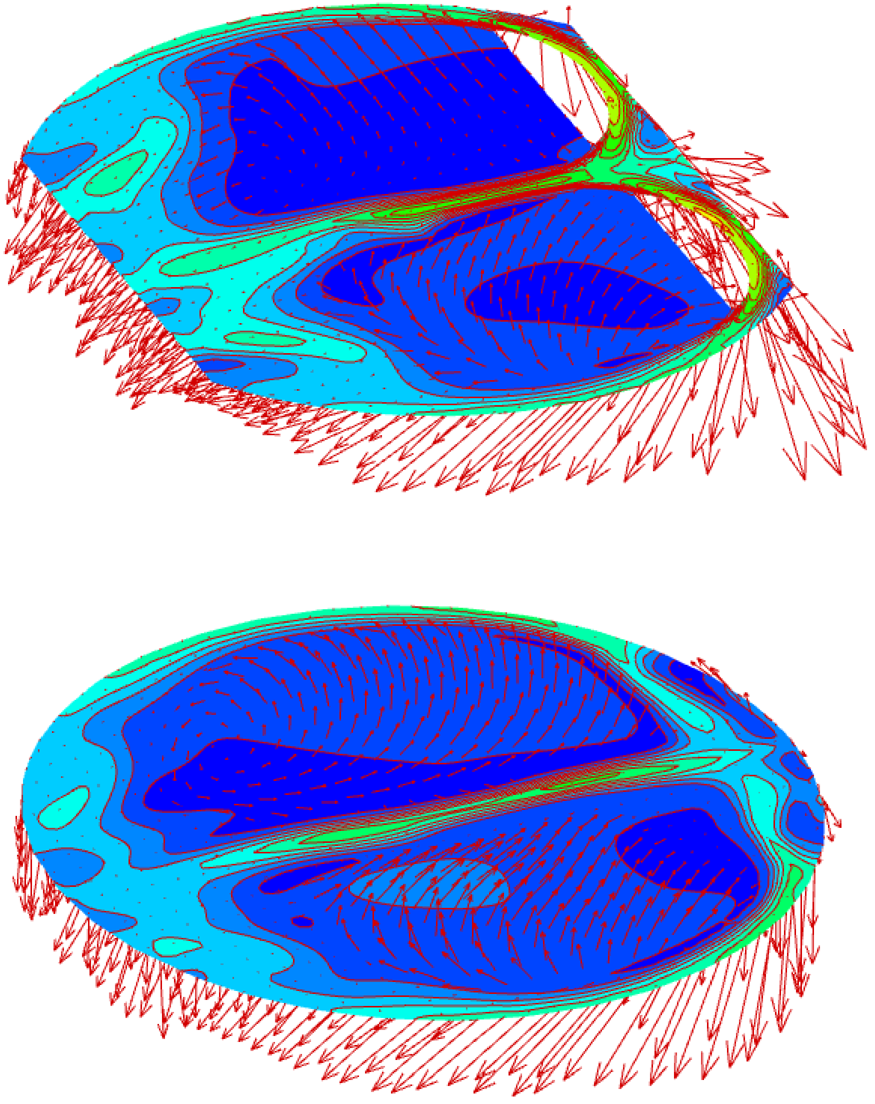
Results – Detailed Section Views – Intake at 3mm



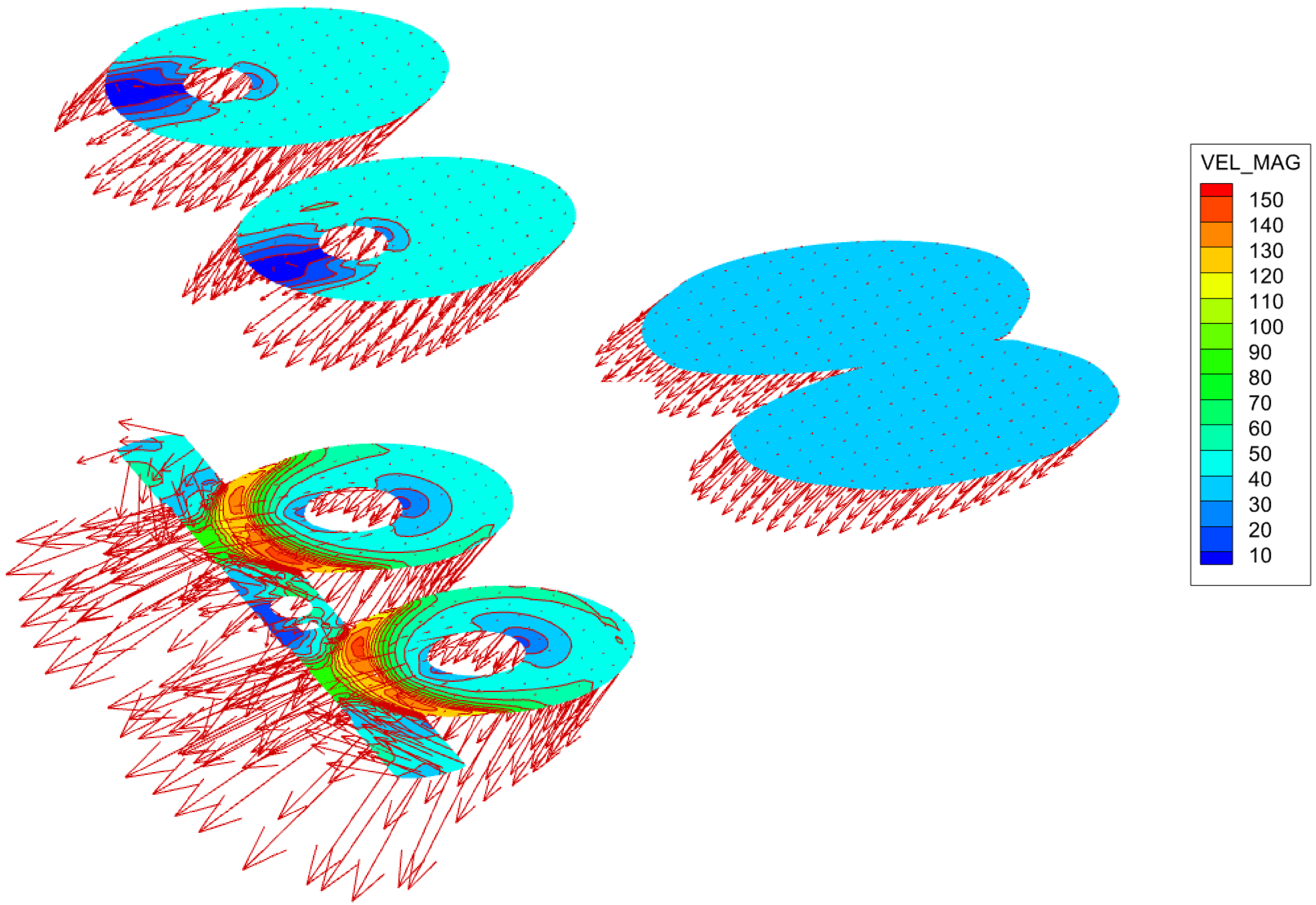
Section thru spark plug



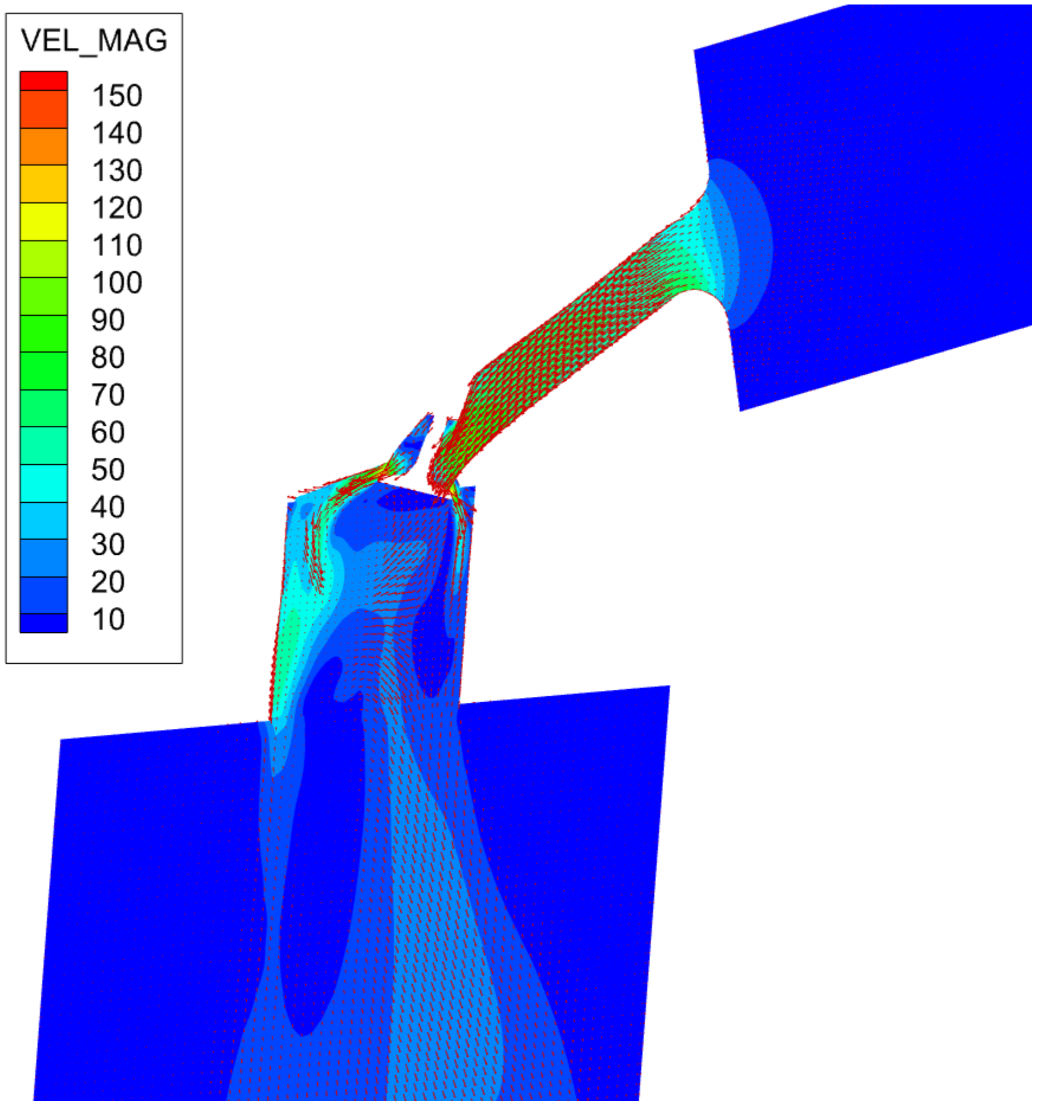
Results – Detailed Section Views – Intake at 3mm



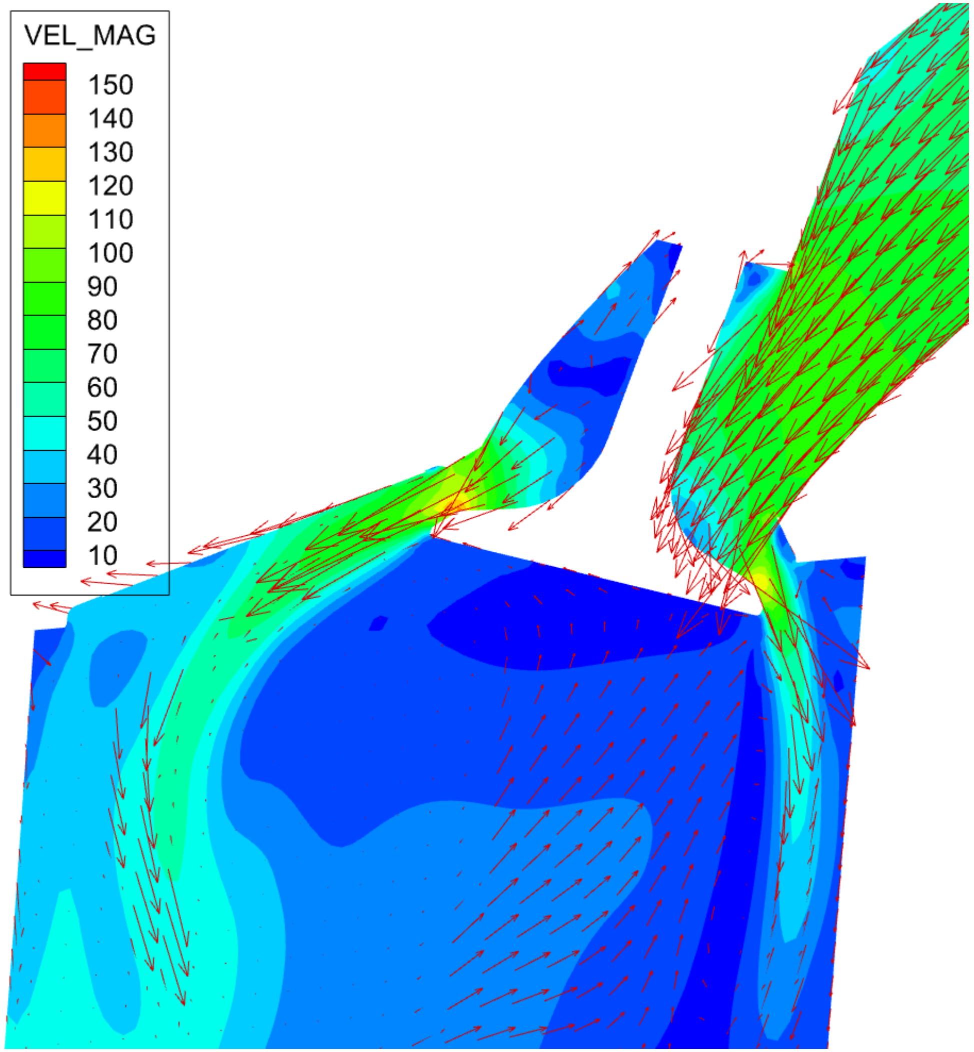
Horizontal Sections



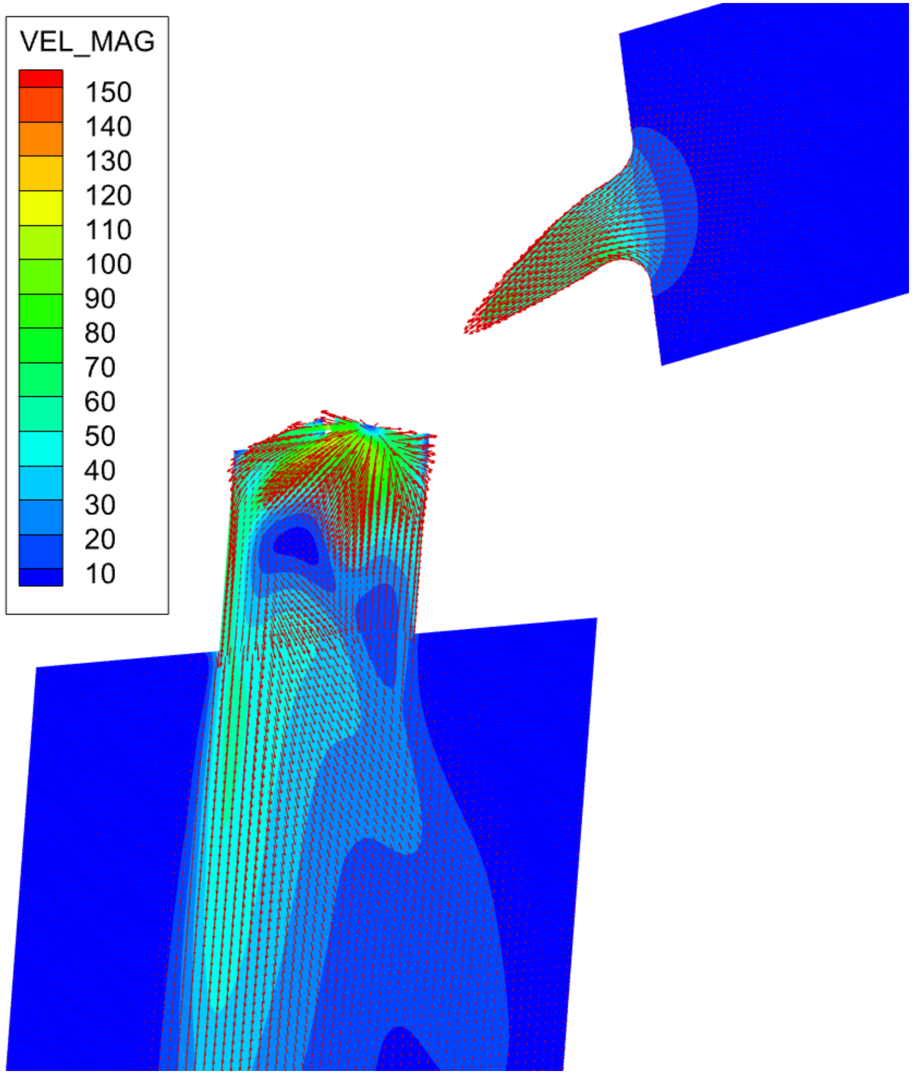
Results – Detailed Section Views – Intake at 6mm



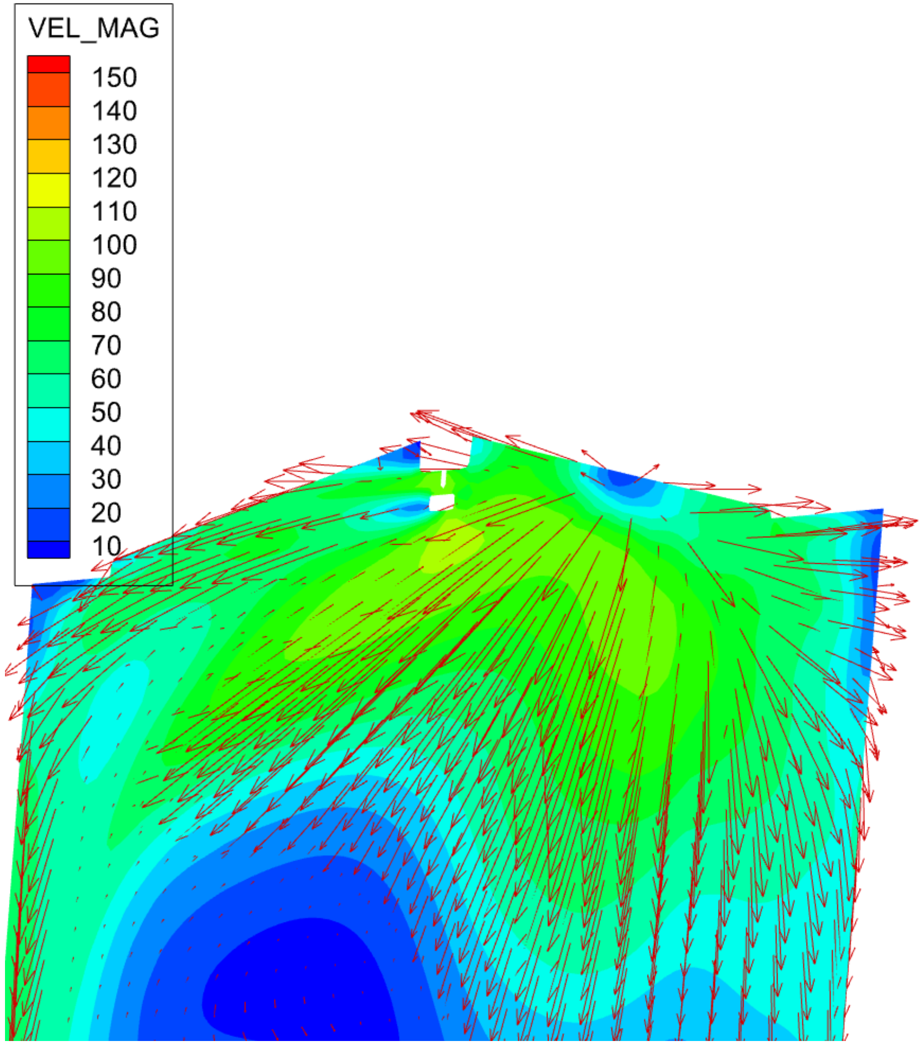
Section thru valve



Results – Detailed Section Views – Intake at 6mm

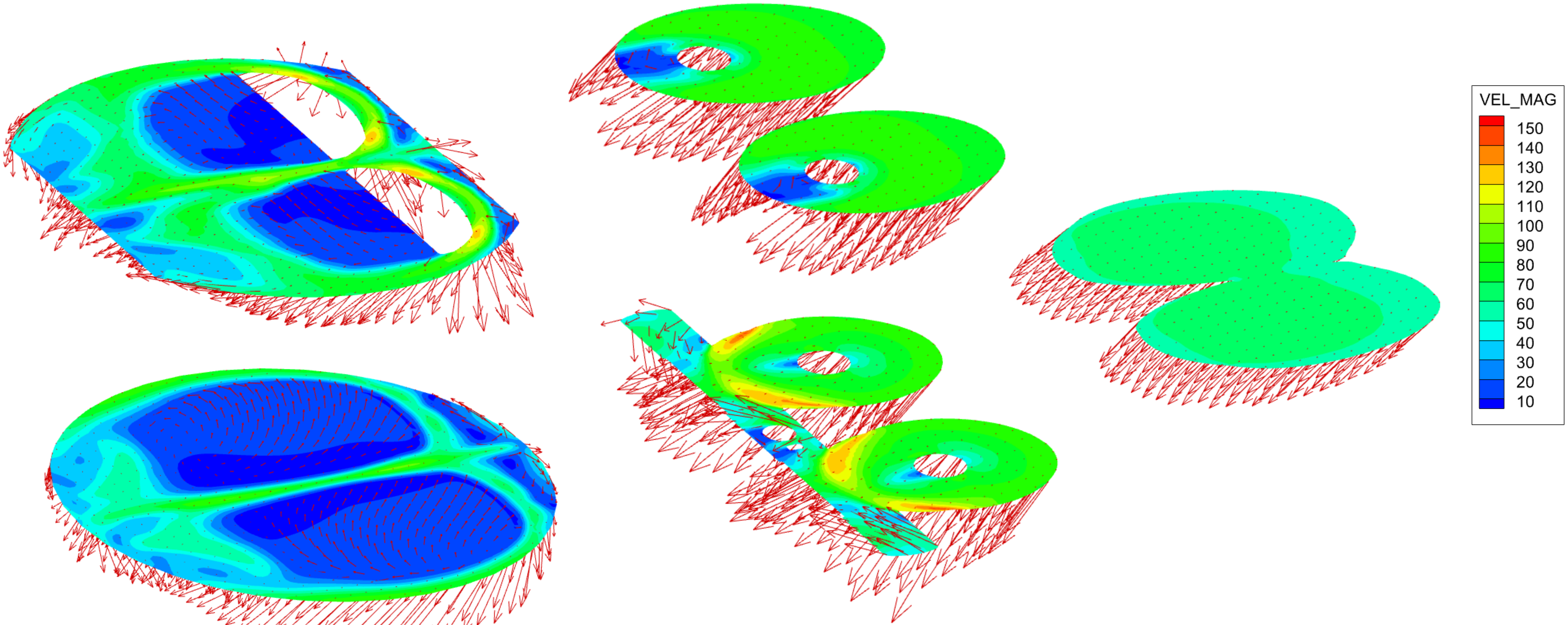


Section thru spark plug



Results – Detailed Section Views – Intake at 6mm

Horizontal Sections



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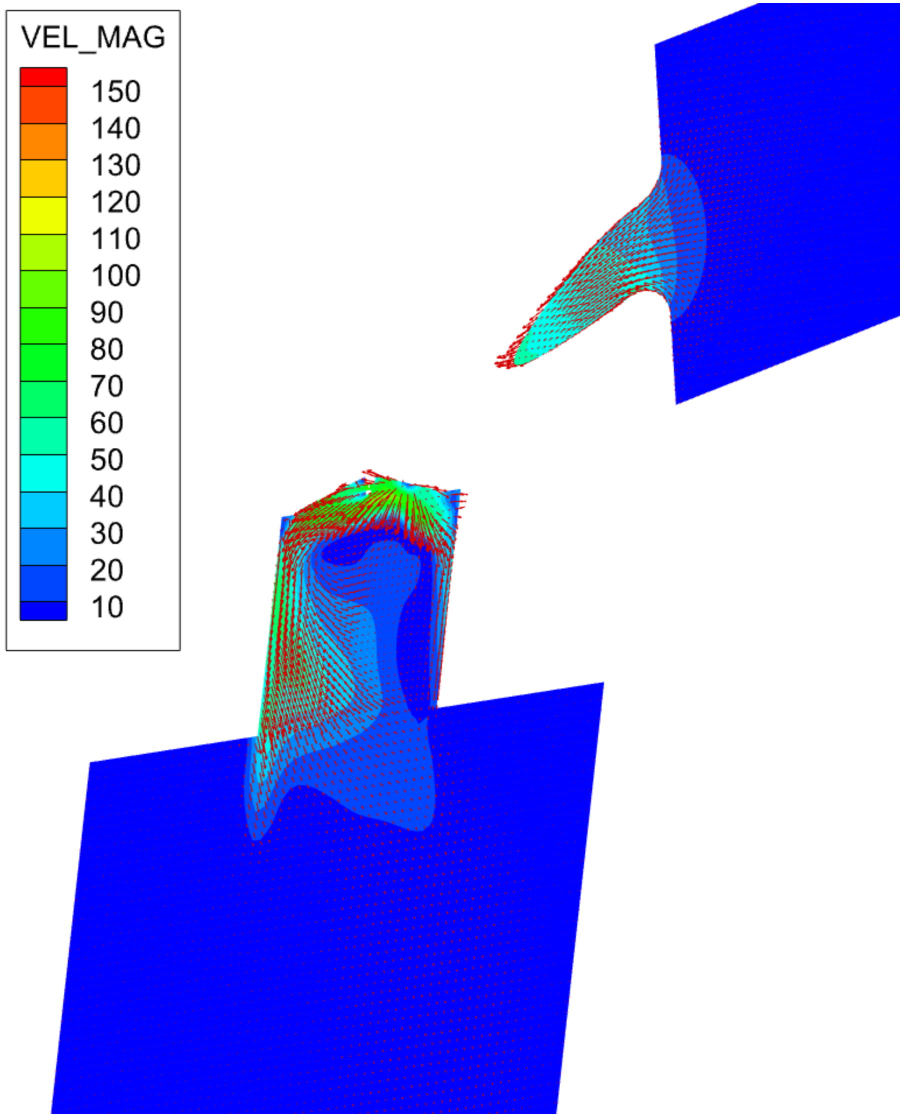
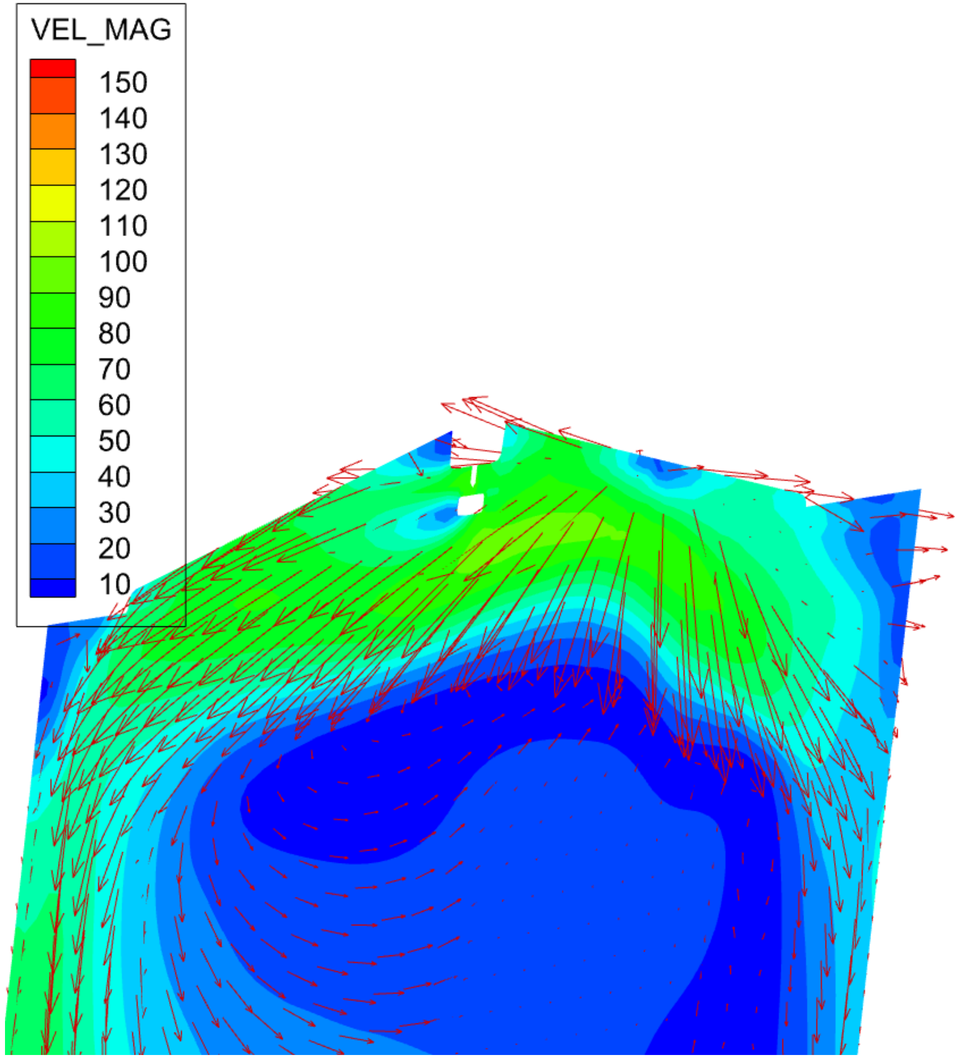
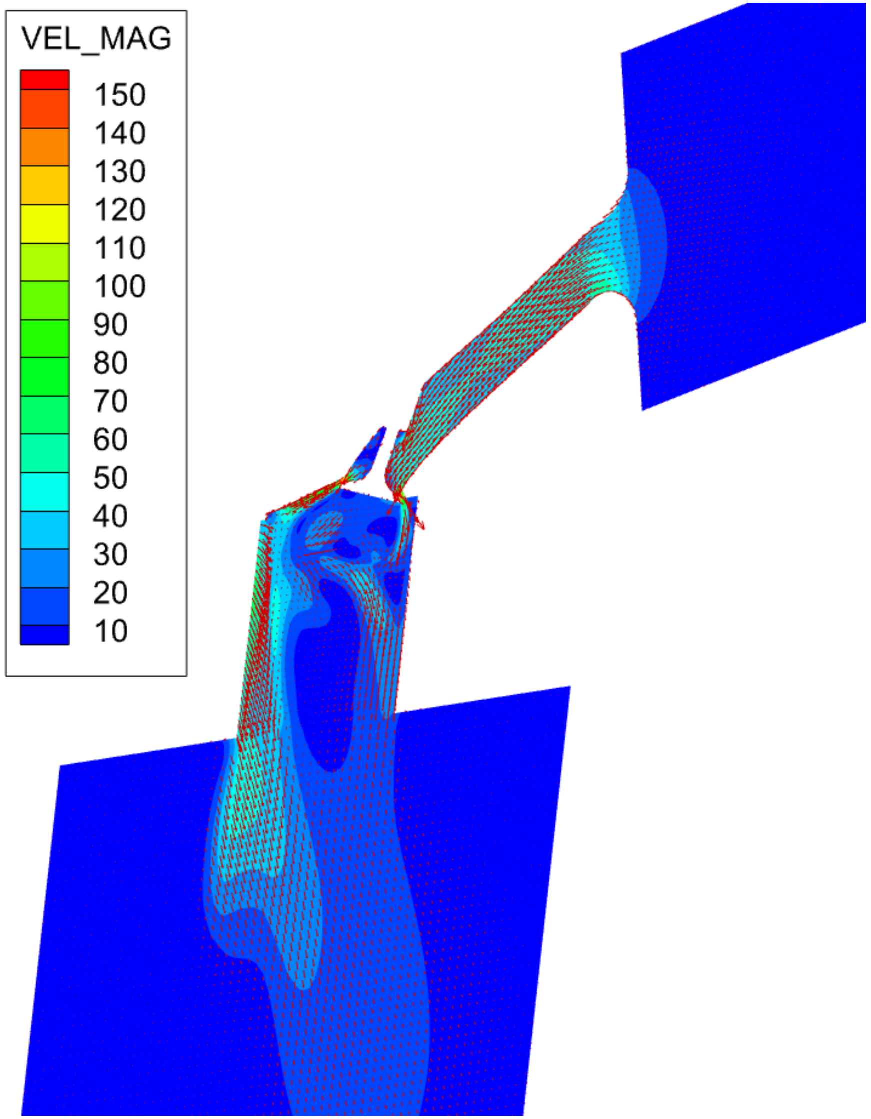
Results – Detailed Section Views – Intake at 3 and 6mm



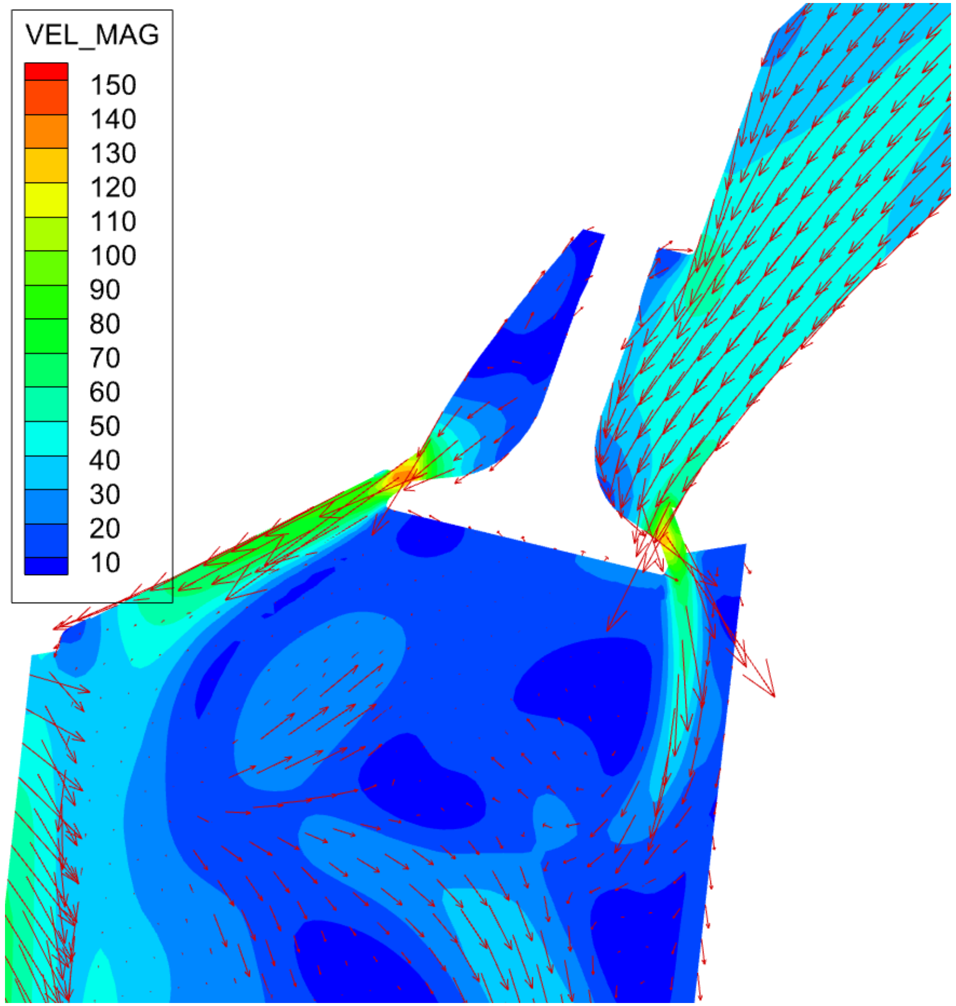
Section thru spark plug



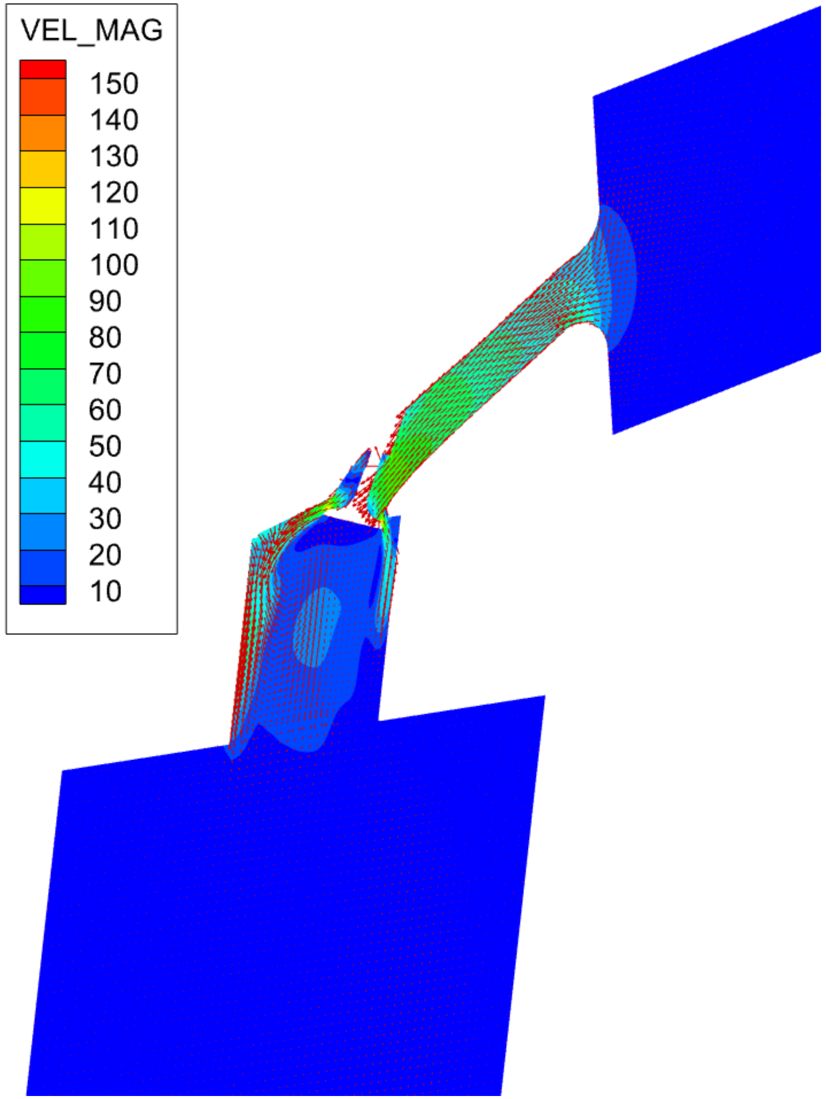
Results – Detailed Section Views – Intake at 3 and 6mm



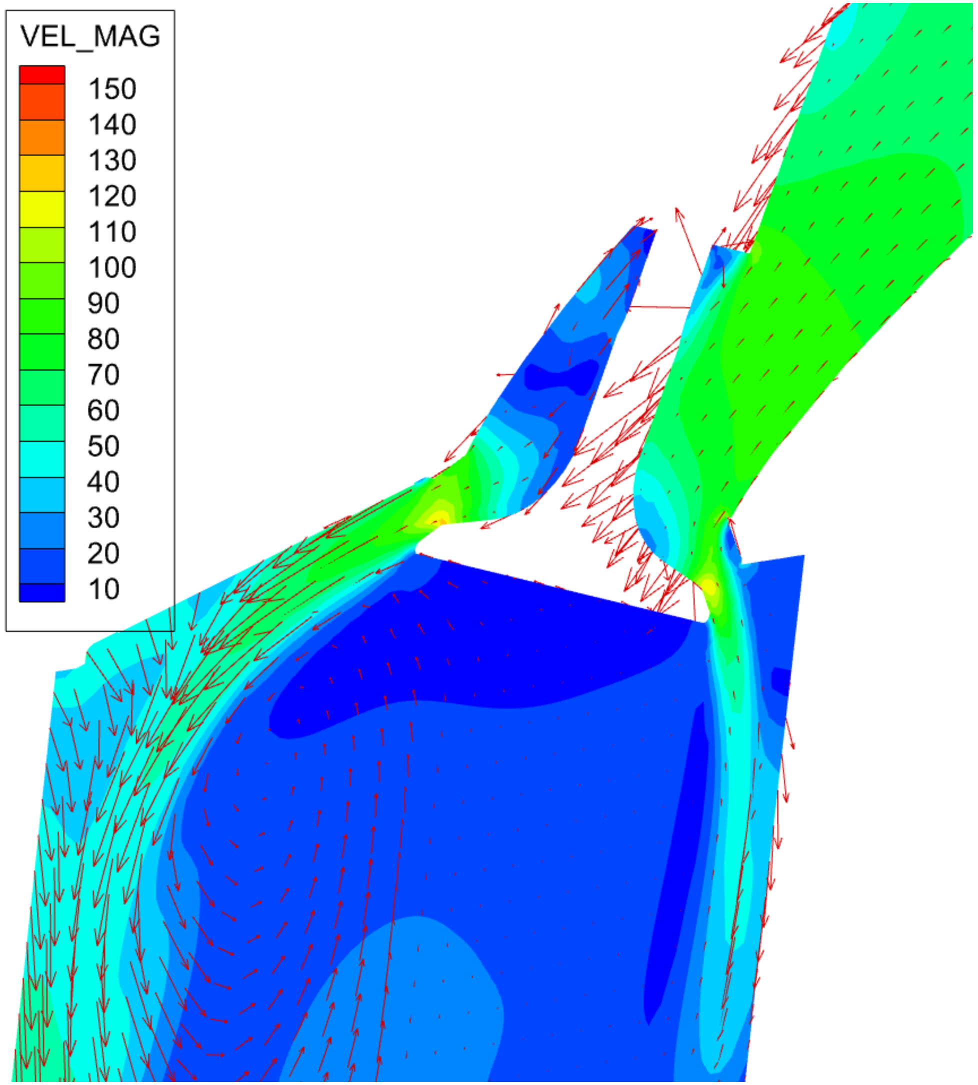
Section thru 3mm valve



Results – Detailed Section Views – Intake at 3 and 6mm

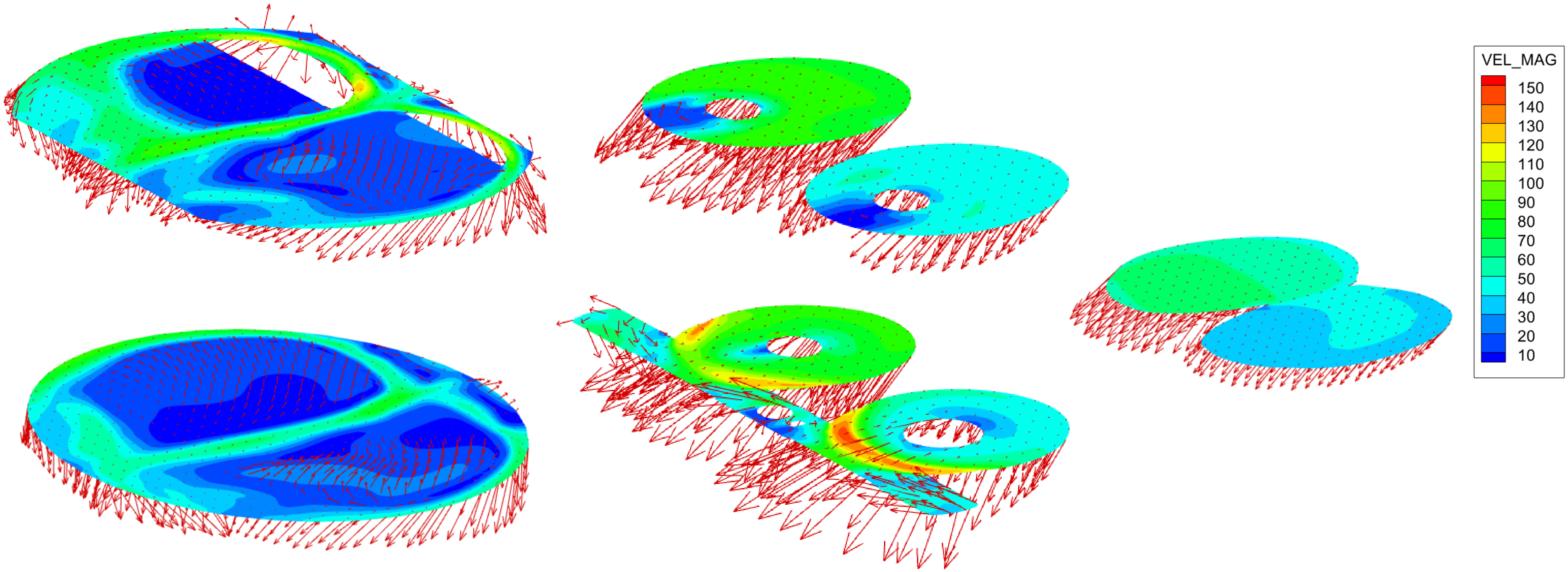


Section thru 6mm valve



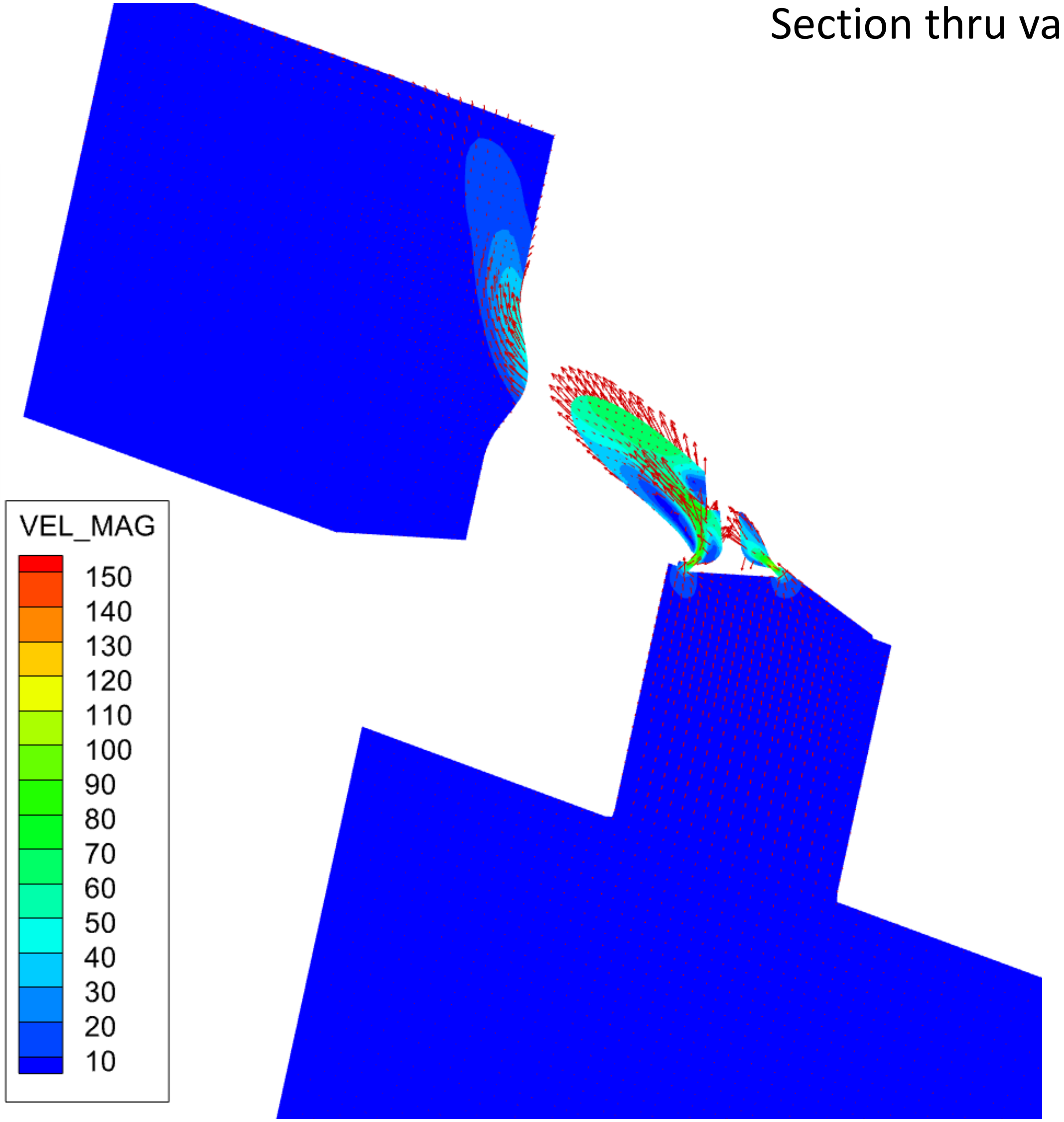
Results – Detailed Section Views – Intake at 3 and 6mm

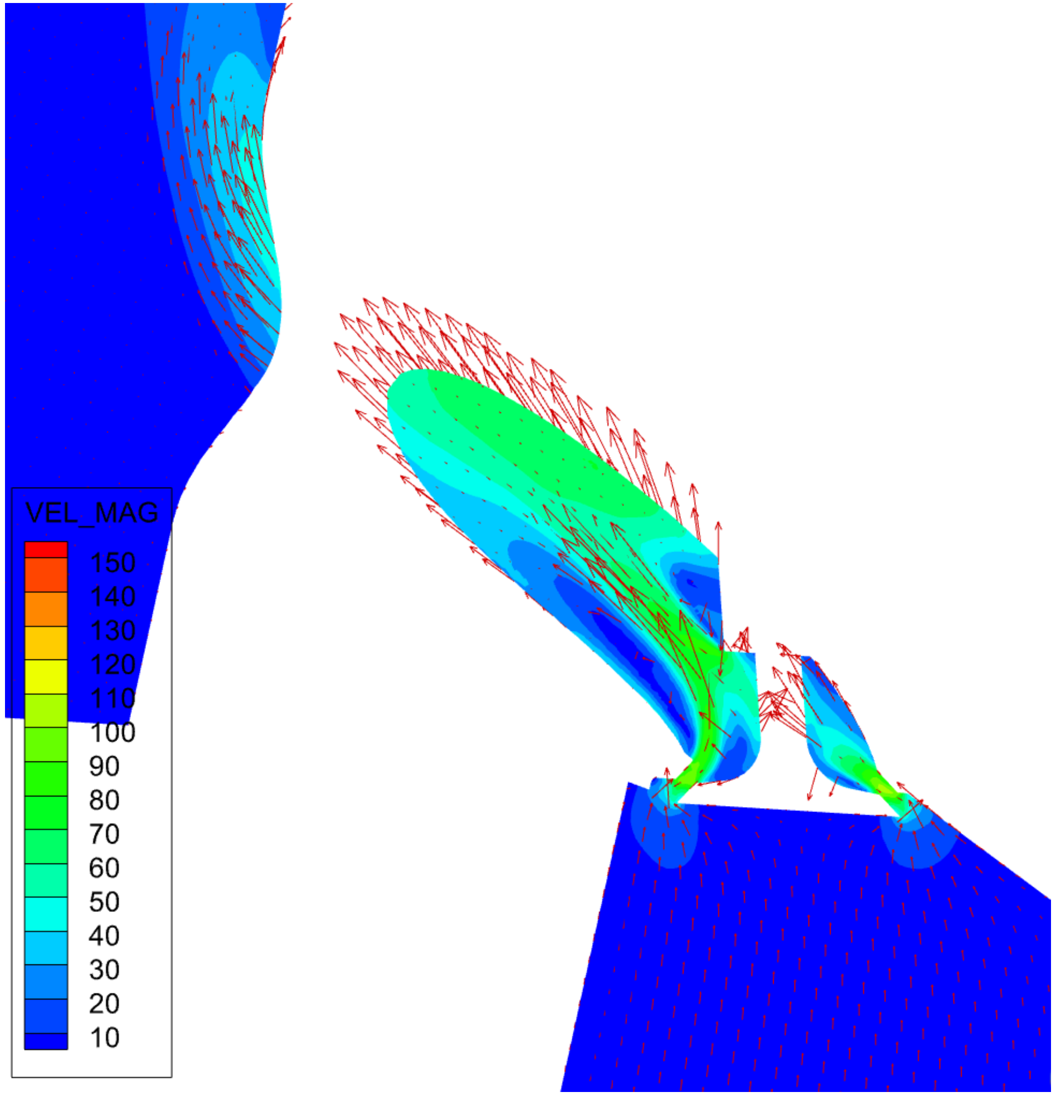
Horizontal Sections



Results – Detailed Section Views – Exhaust at 3mm

Section thru valve





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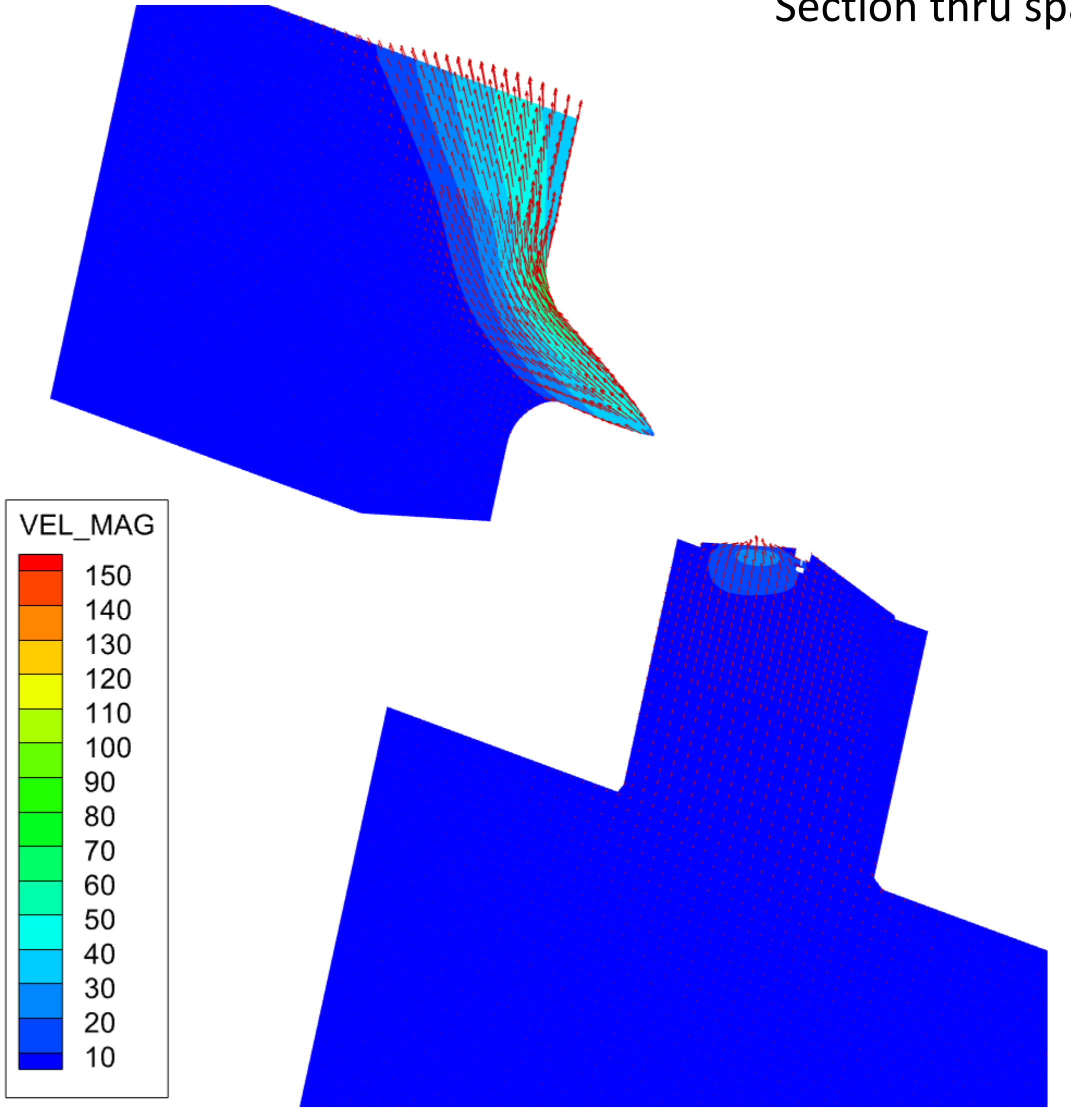
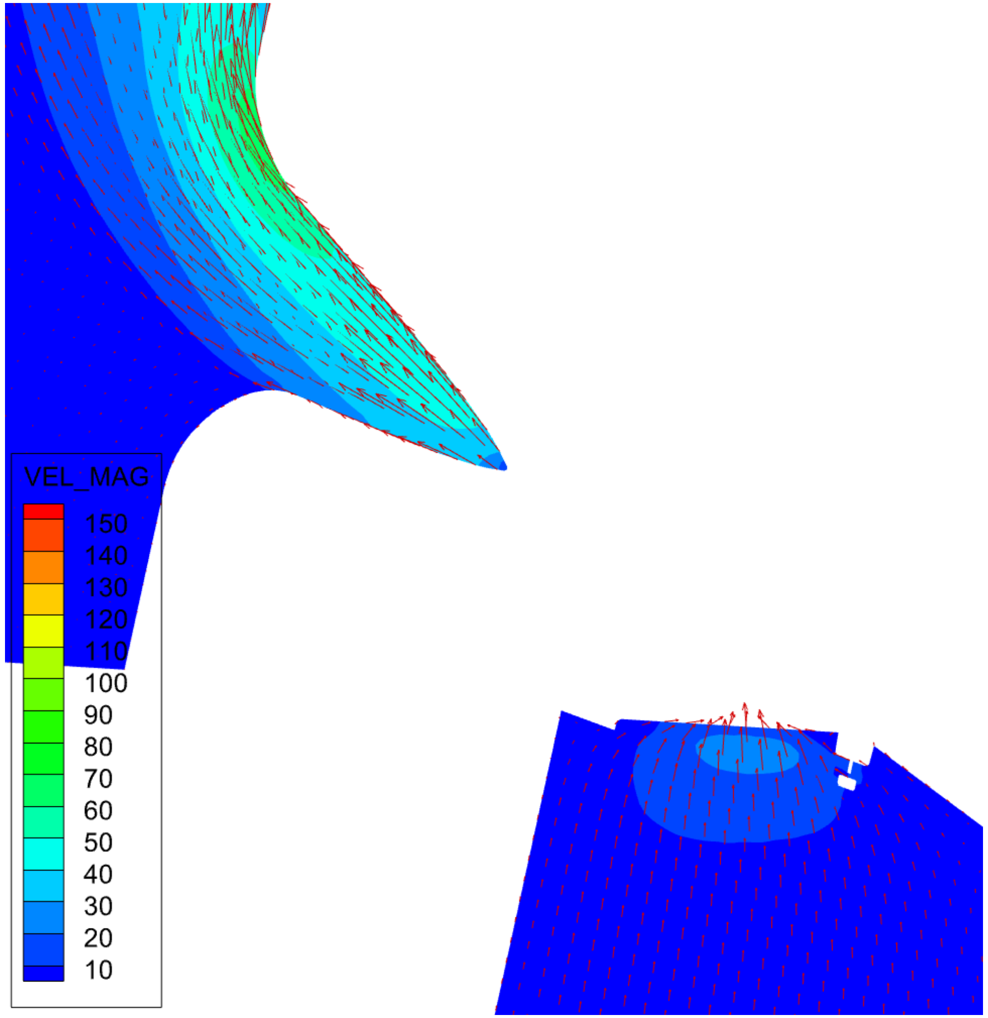
Results – Detailed Section Views – Exhaust at 3mm

Section thru spark plug





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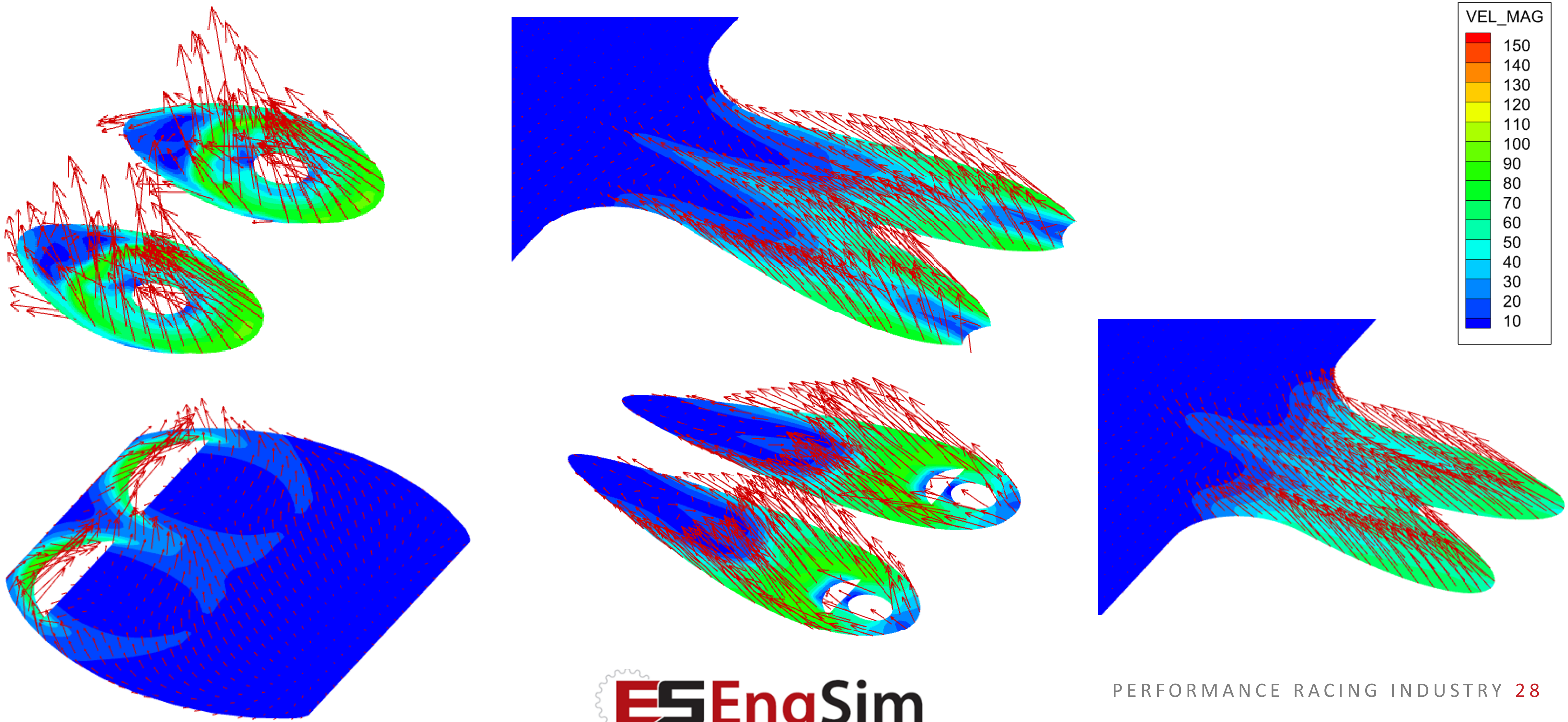
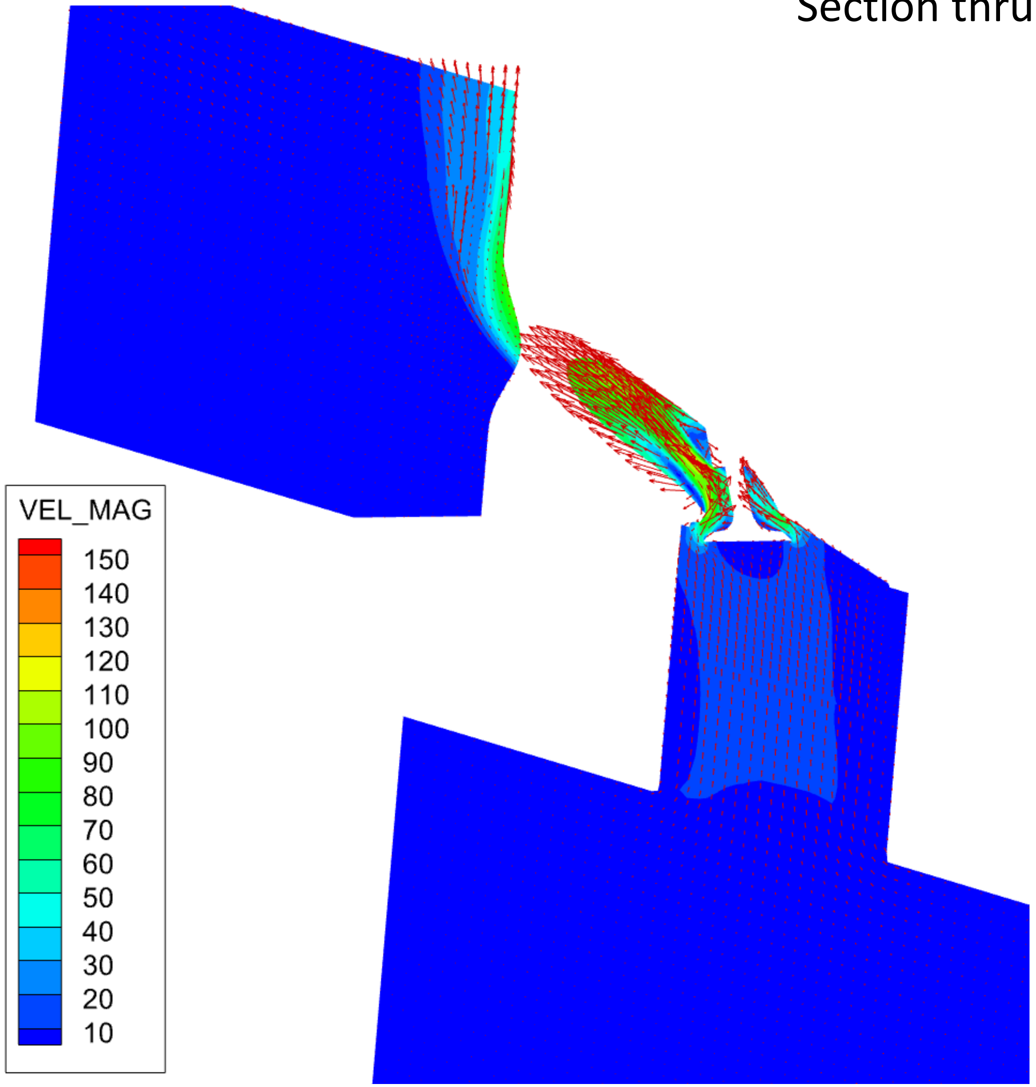
Results – Detailed Section Views – Exhaust 3mm

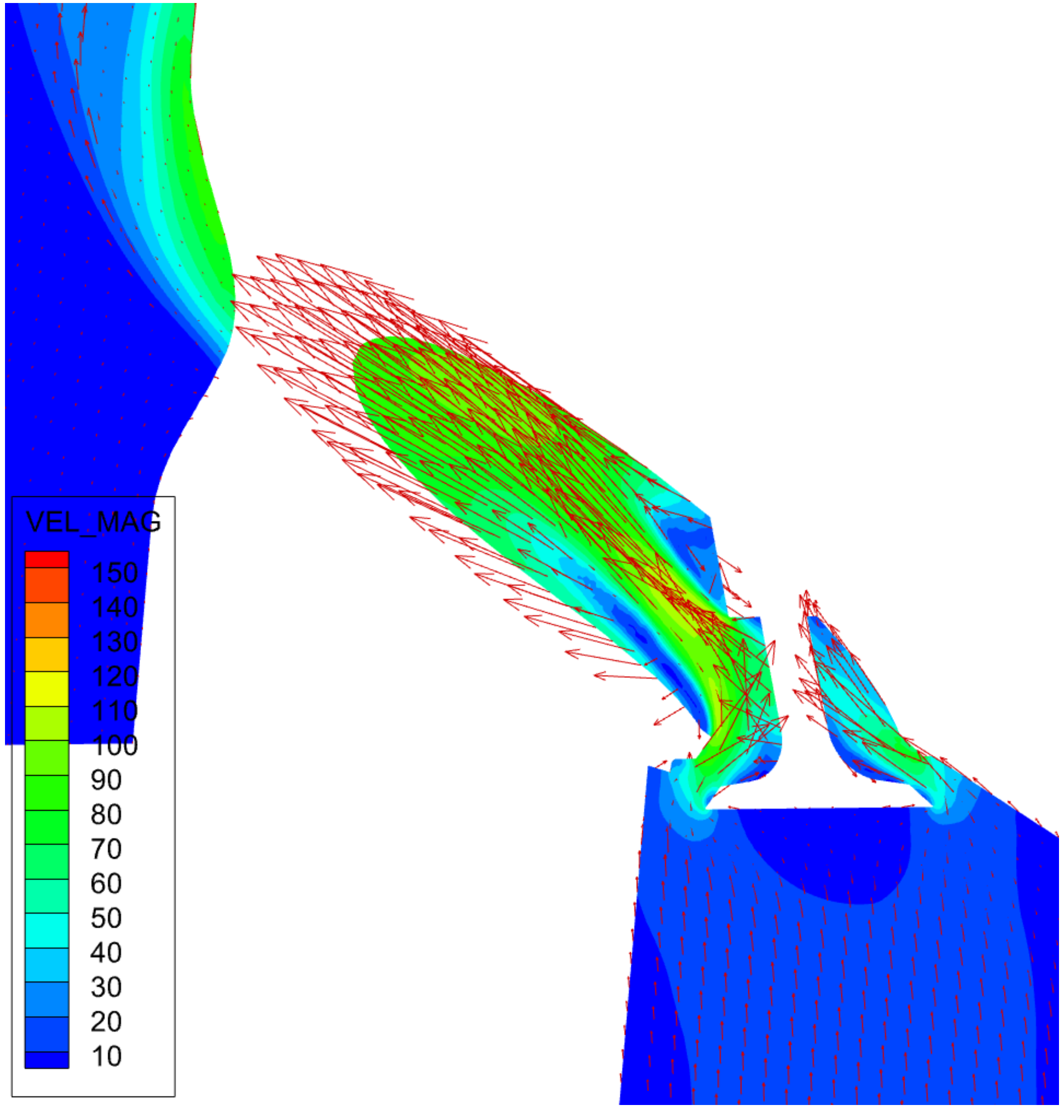
Horizontal Sections



Results – Detailed Section Views – Exhaust at 6mm

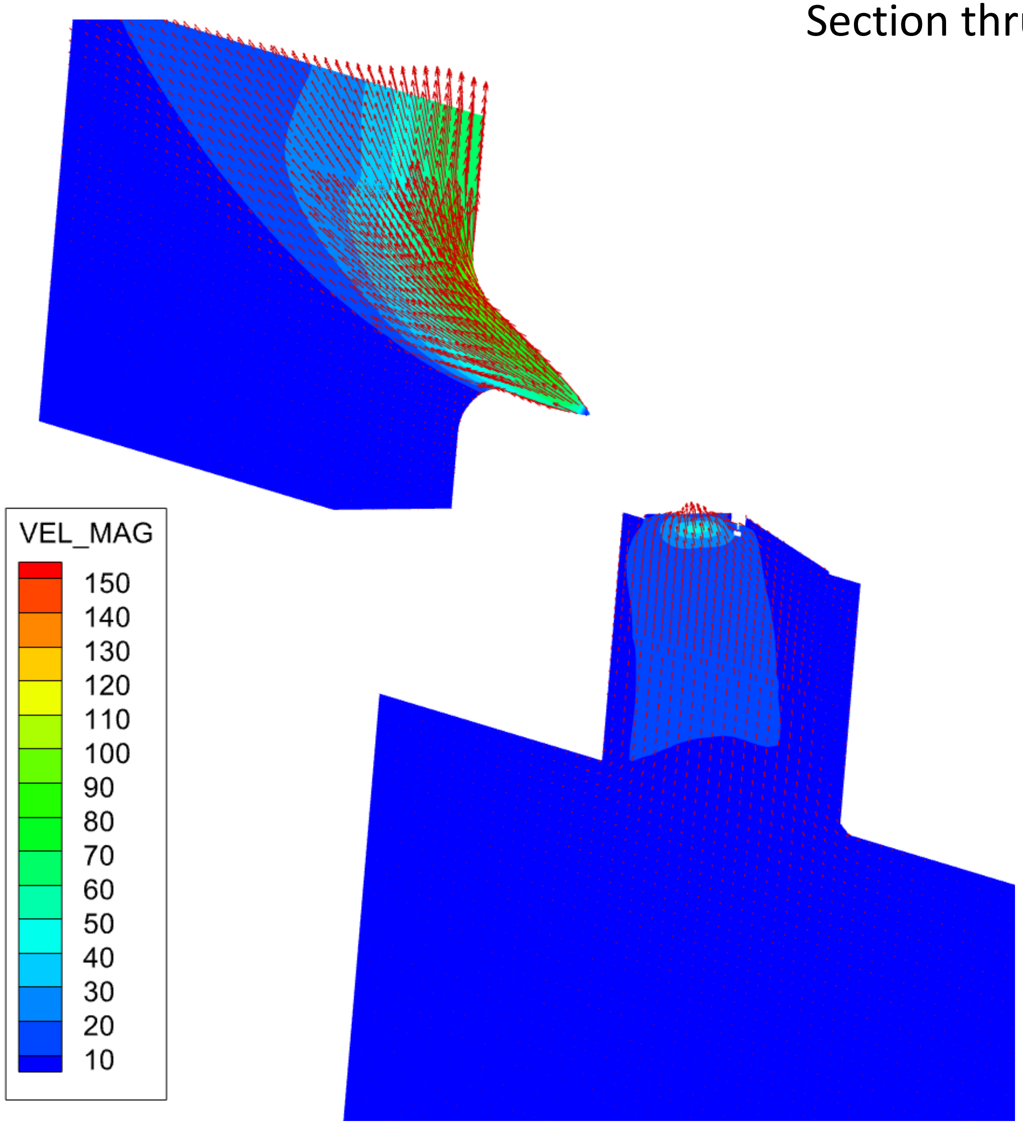
Section thru valve

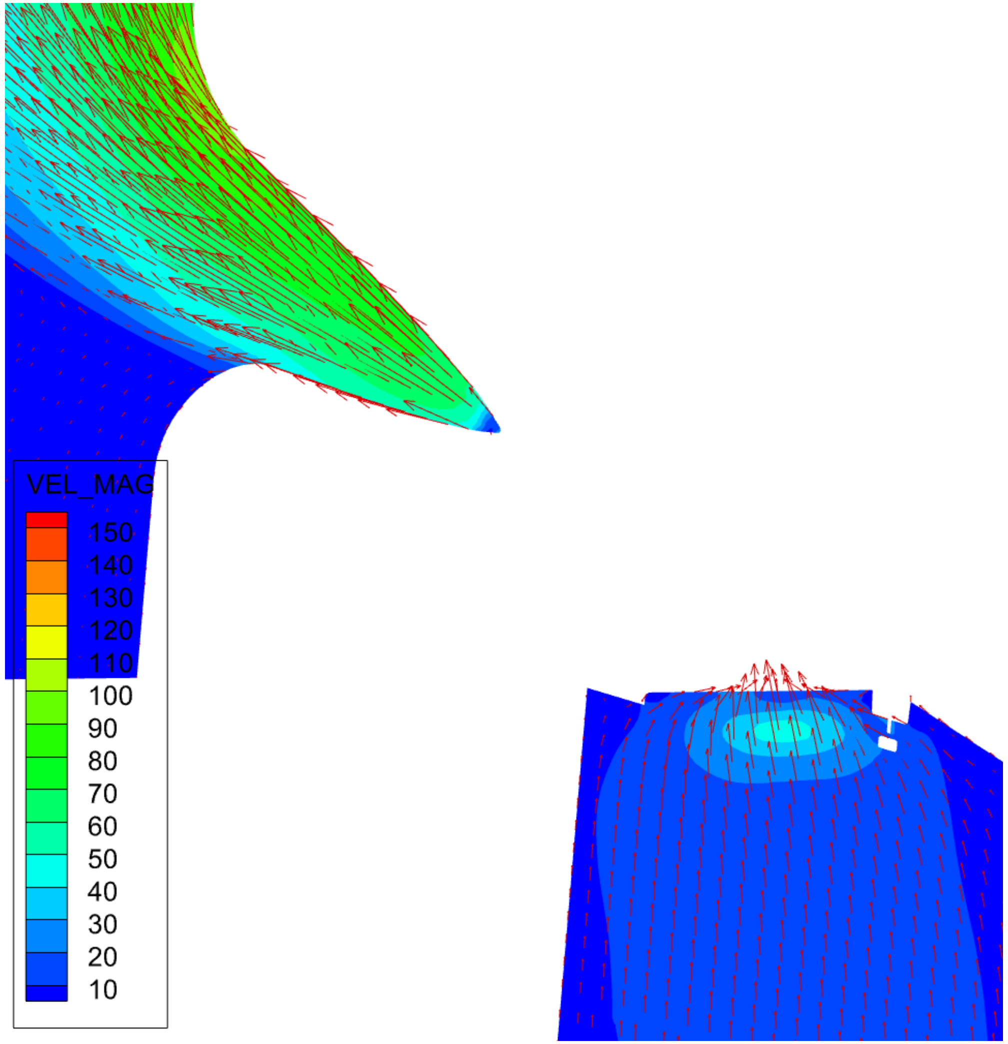




Results – Detailed Section Views – Exhaust at 6mm

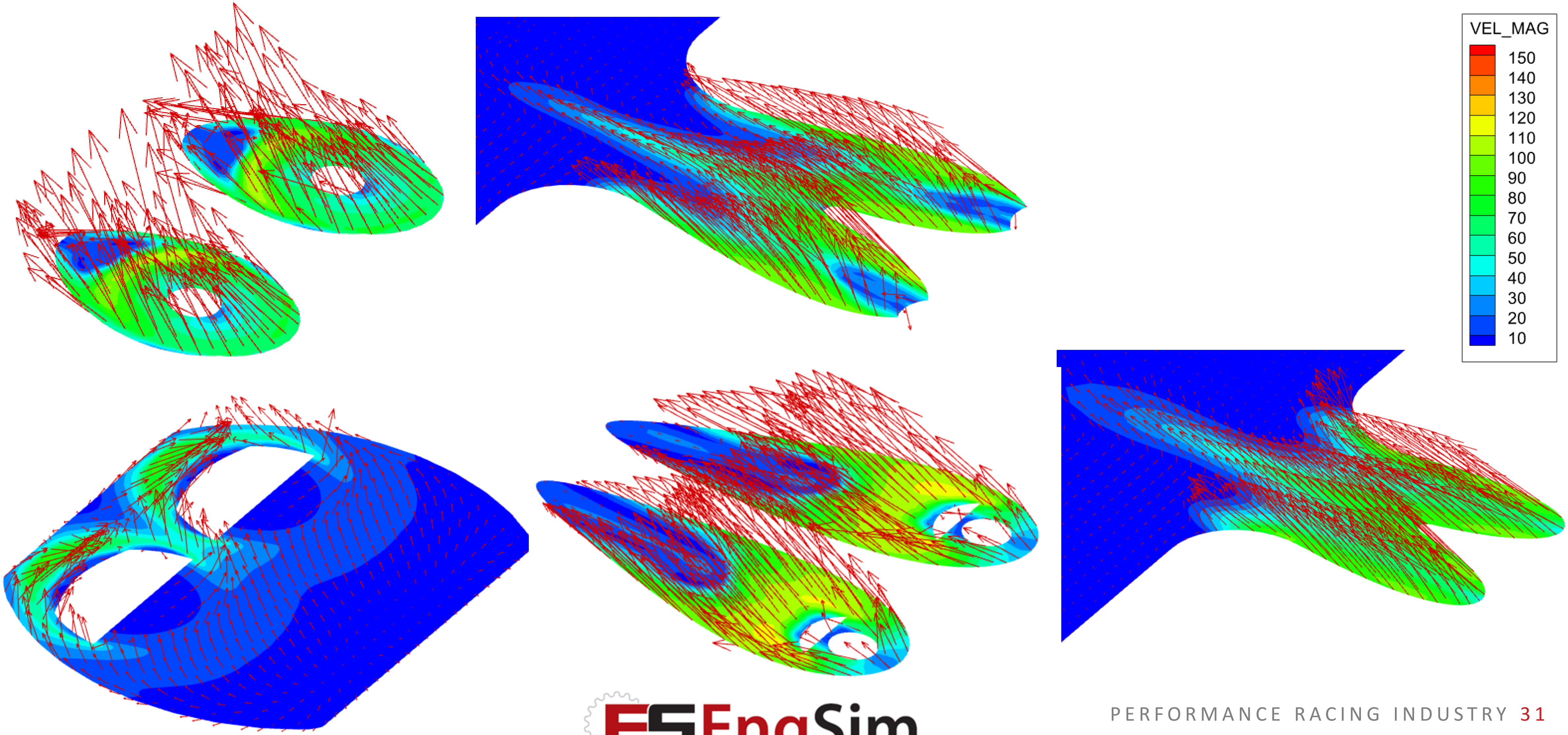
Section thru spark plug





Results – Detailed Section Views – Exhaust 6mm

Horizontal Sections



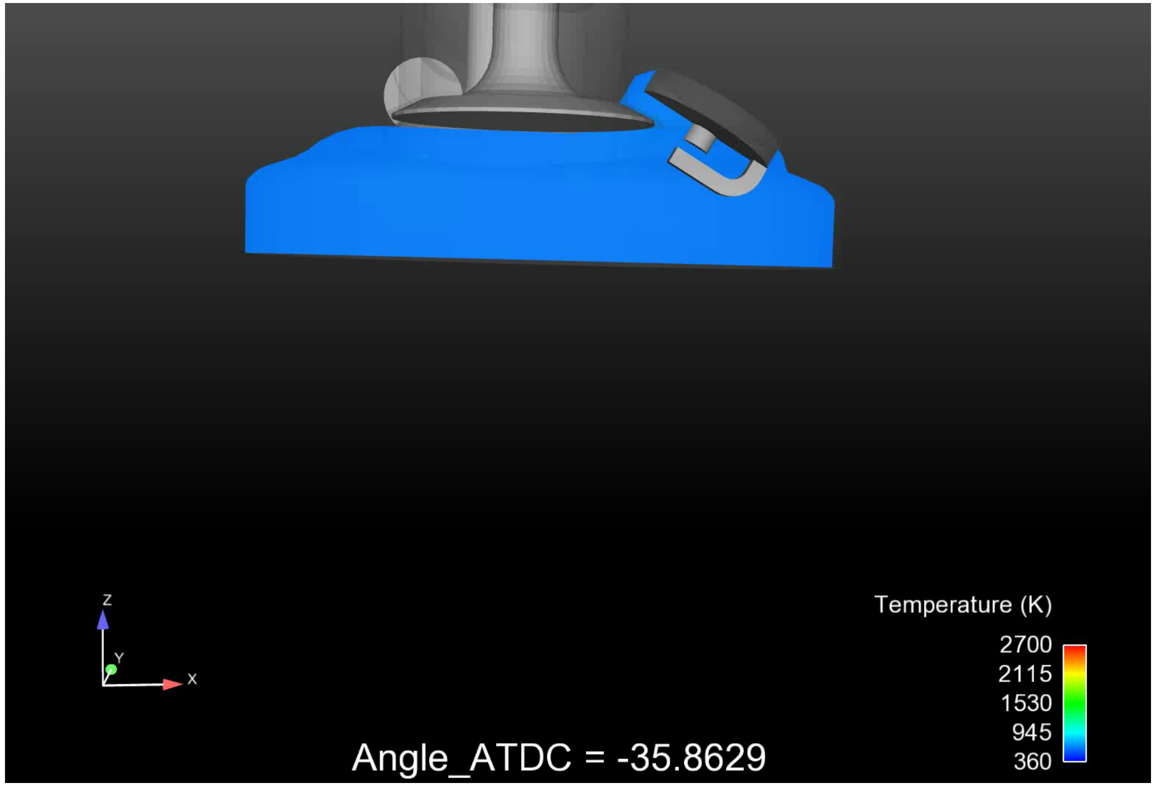
Results – Observations and Conclusions

1. Intake port flow
   a. Cd's indicate that the flow capacity could likely need improvement (1).
   b. Visualization indicates typical flow regions and character and set up good potential for tumble mixture motion and no overall swirl.
   c. Valve seat area could use development to reduce flow recirculation.
   d. As expected, the 3 and 6mm combination of valve lift generated moderate "twirl".
2. Exhaust port flow
   a. Cd's indicate that the flow capacity could likely need improvement (1).
   b. Short side flow detaches quickly and pushes flow to the port roof.
   c. Valve seat area could use development to better reduce flow recirculation.
   d. Further modeling should incorporate a section of the exhaust pipe for better port exit representation and potentially a larger exit plenum.

Summary – Logical Next Steps

1. Investigate higher pressure/vacuum ranges for steady flow modeling to see how it changes results and development direction.
2. Take these models here and move into transient “cold” flow, then full combustion modeling.
3. Add in manifolds to transient modeling to see cylinder-to-cylinder effects – usually very enlightening.

Full Moving Piston/Valves Transient with Combustion



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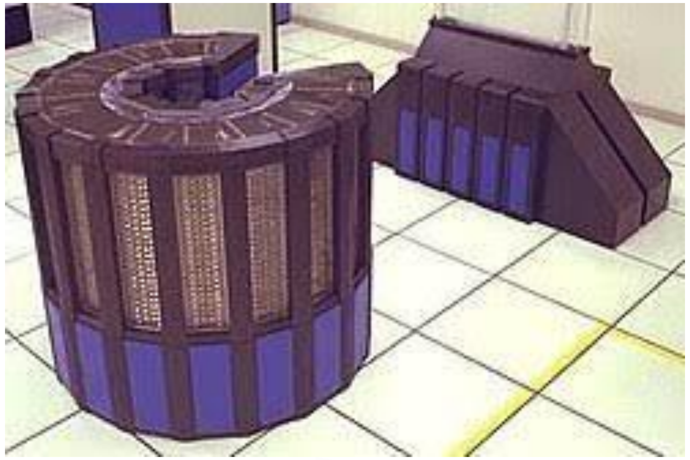
Summary - Outlook

1. The Industry will see continued and rapid evolution.
   a. Speed and ease of use.
2. Continued development of combustion, emissions, and exhaust aftertreatment sub-models.
3. More “Integrated Modeling”
   a. Multi-domain – combining 1-D with 3-D, chemistry, heat transfer, noise, structural...
   b. Adaptable levels of fidelity – fast and coarse vs less-fast and detailed.
   c. Collaborative across departments and suppliers/OEMs – testing/CAD/CAE/manufacturing/sales-marketing.
4. All this will continue to make simulations an ever increasing “go-to” tool to speed up development, reduce cost, and increase understanding.



References and Contact Info

1. SAE Paper
   a. *What is Limiting Your Engine Air Flow: Using Normalized Steady Air Flow Bench Data*, SAE 942477, D. Agnew, 1994.
2. *Reference Textbook*
   a. *Gas Flow in the Internal Combustion Engine*, Annand and Roe, 1974.

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Ph: 248-765-1821

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Please scan the QR code on the back of the chair in front of you to access the PRI Show education survey.

Your input will help us measure the effectiveness of our program and guide our content for upcoming PRI Education programming.

Thank you for attending!

Appendix – High Pressure/Vacuum Cases

Intake Port at 6mm and 10.7 kPa, 352K (88 inH2O, 173F)

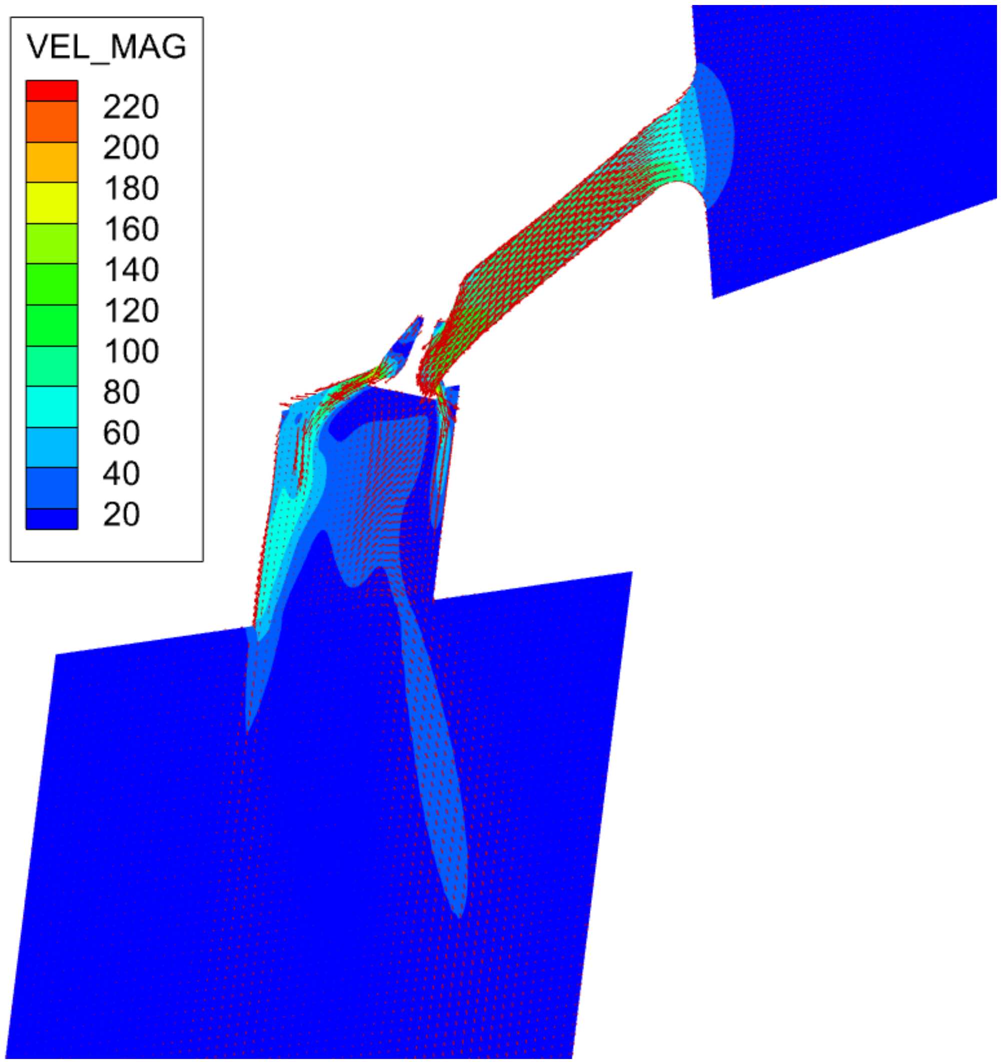
100 g/s

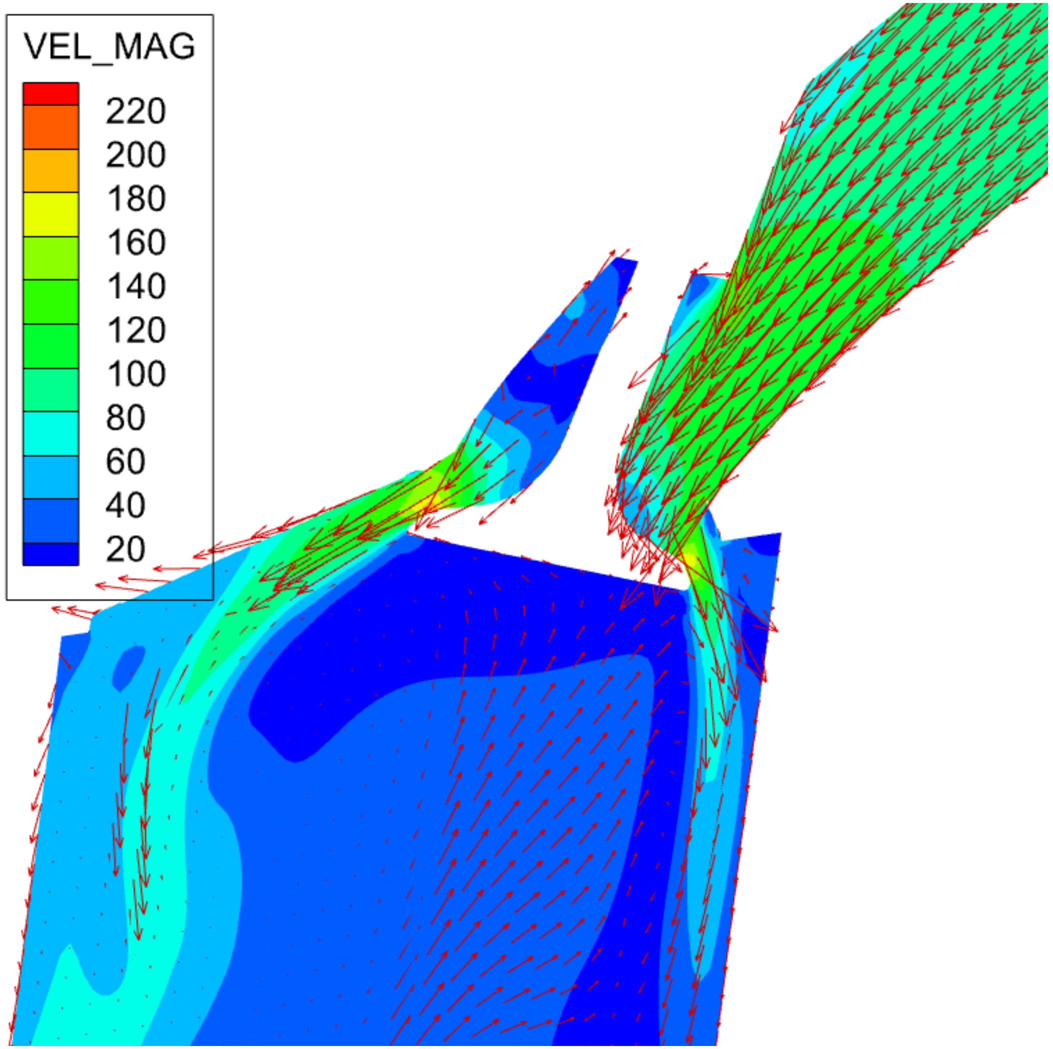
Exhaust Port at 3mm and 133 kPa, 927K (900 inH2O, 1029F)

178 g/s

Results – Detailed Section Views – Intake at 6mm

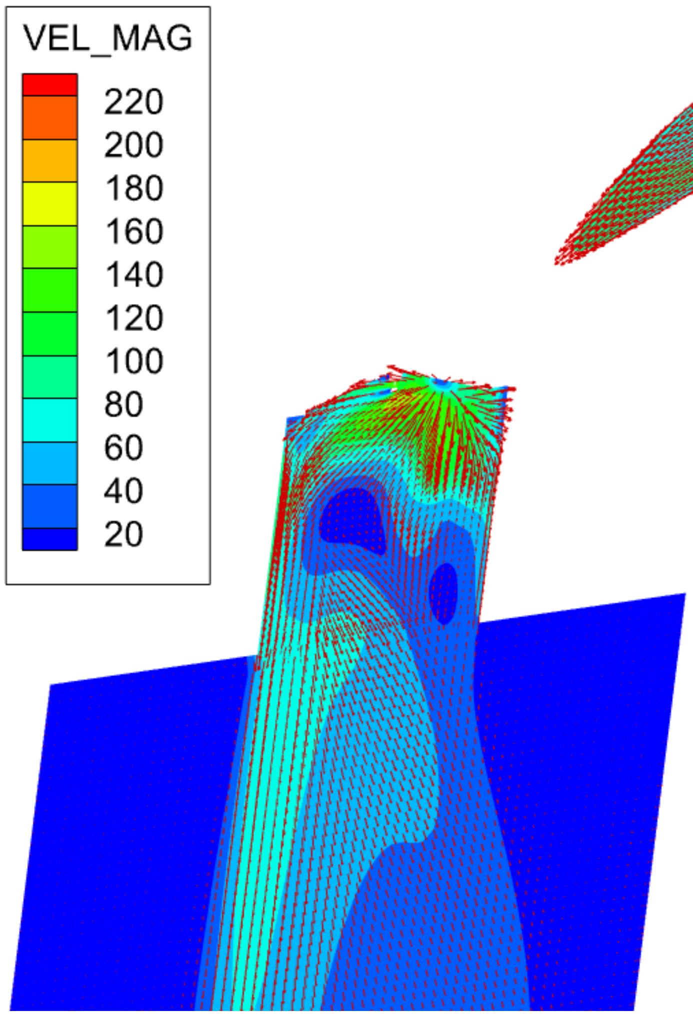
Section thru valve

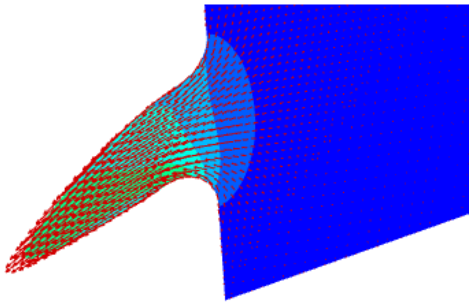


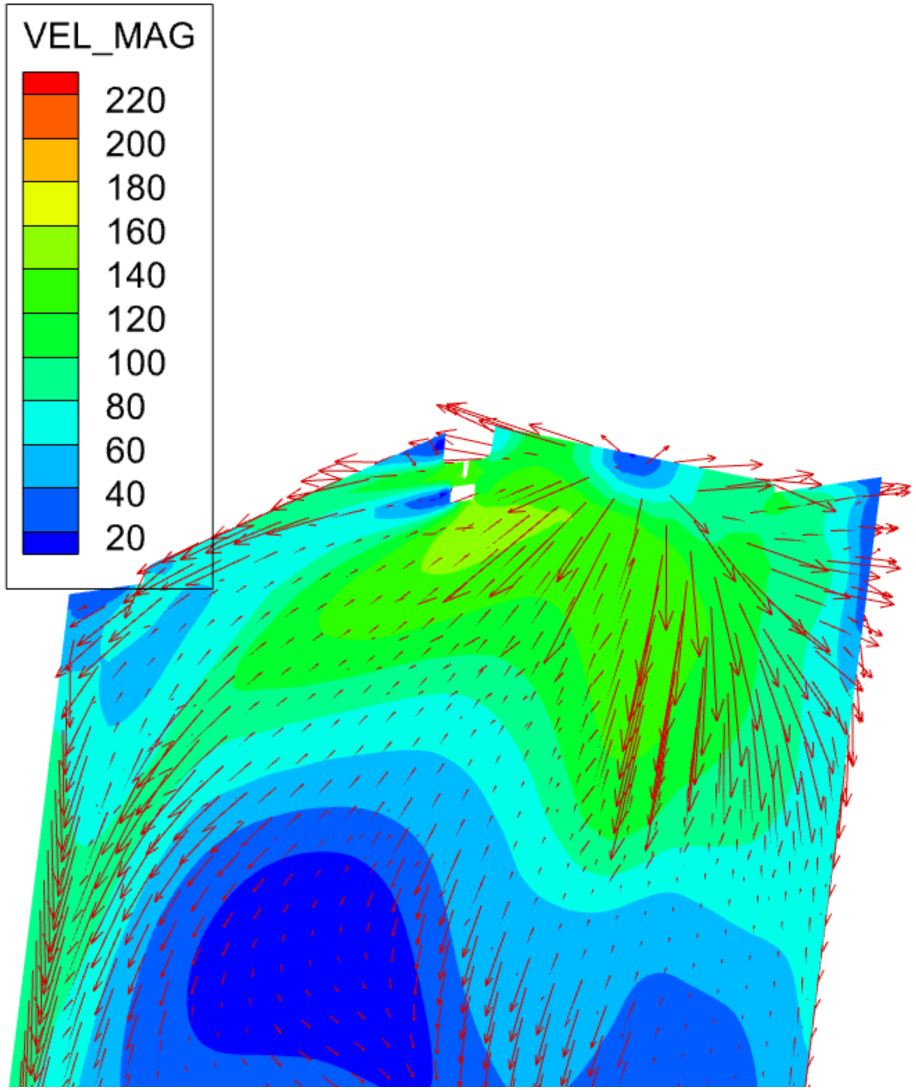


Results – Detailed Section Views – Intake at 6mm

Section thru spark plug

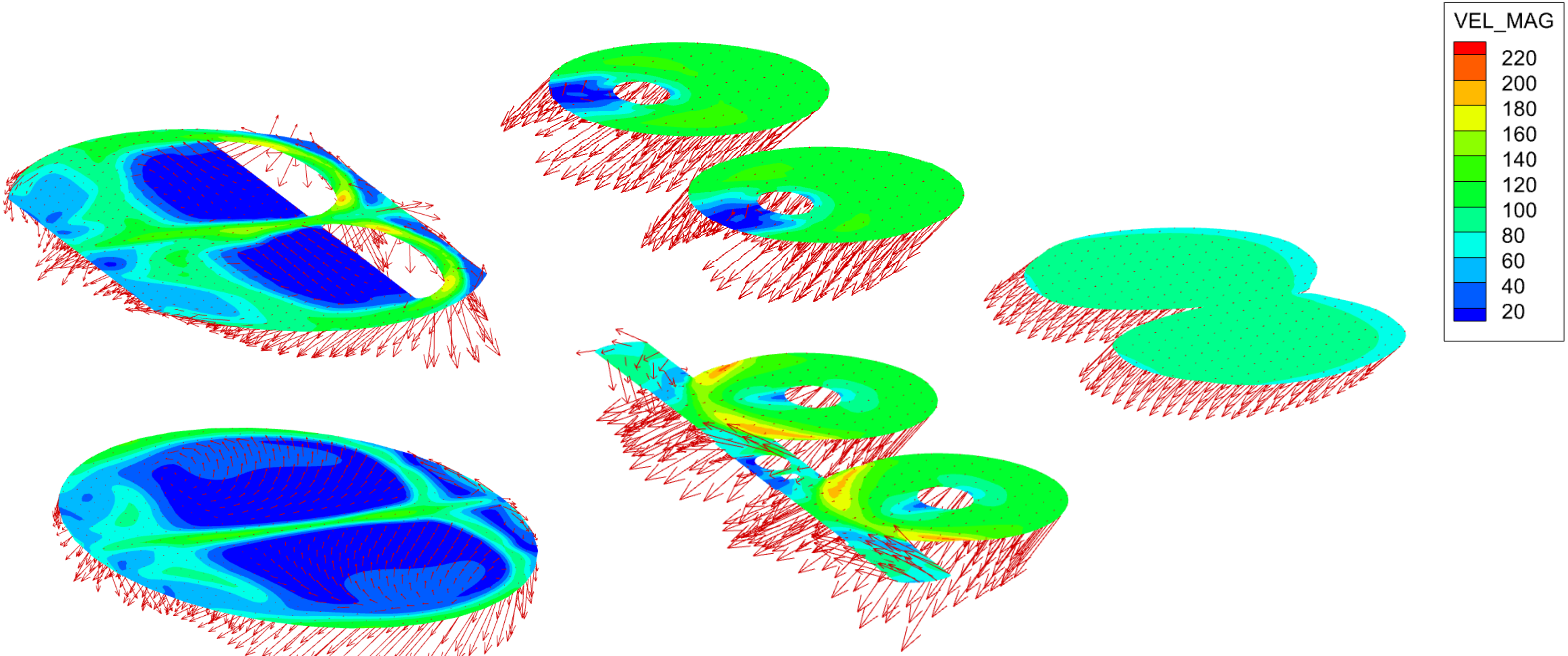






Results – Detailed Section Views – Intake 6mm

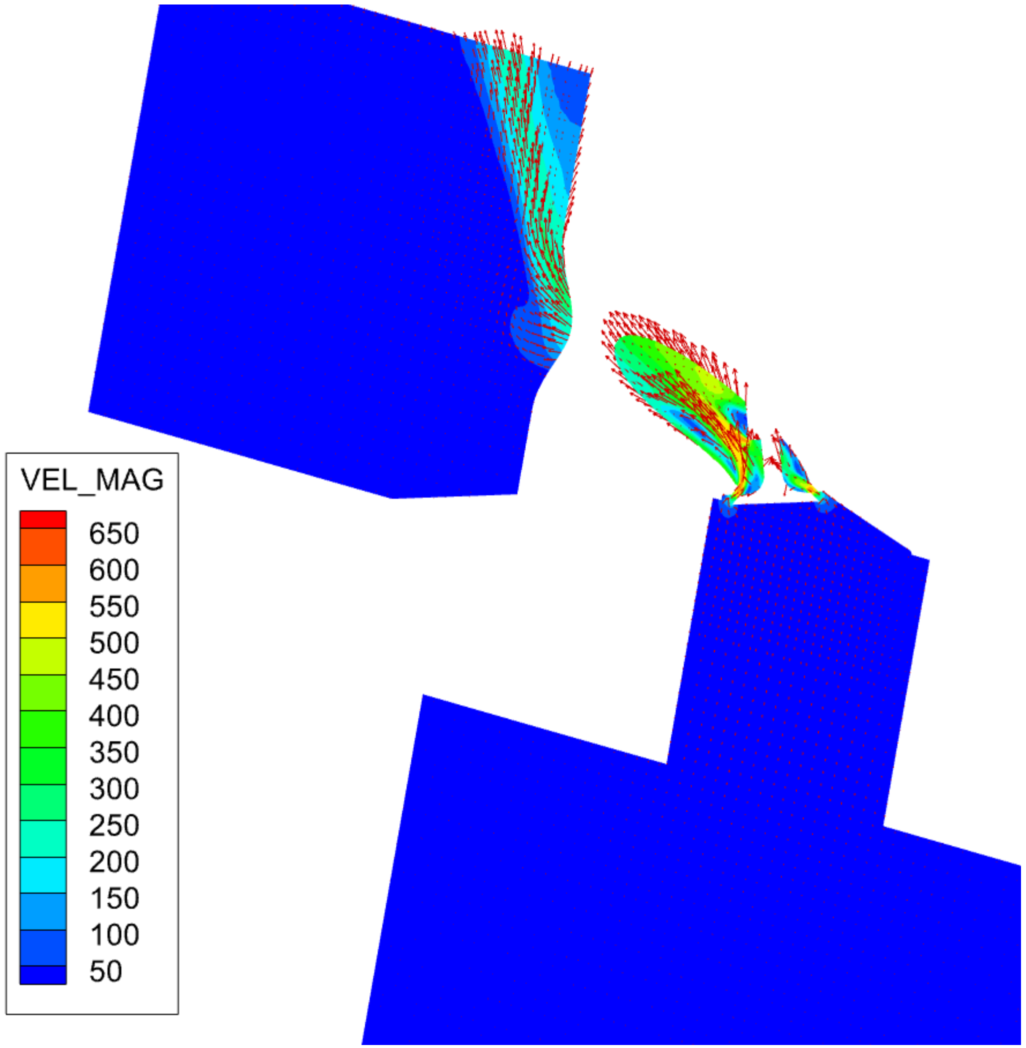
Horizontal Sections

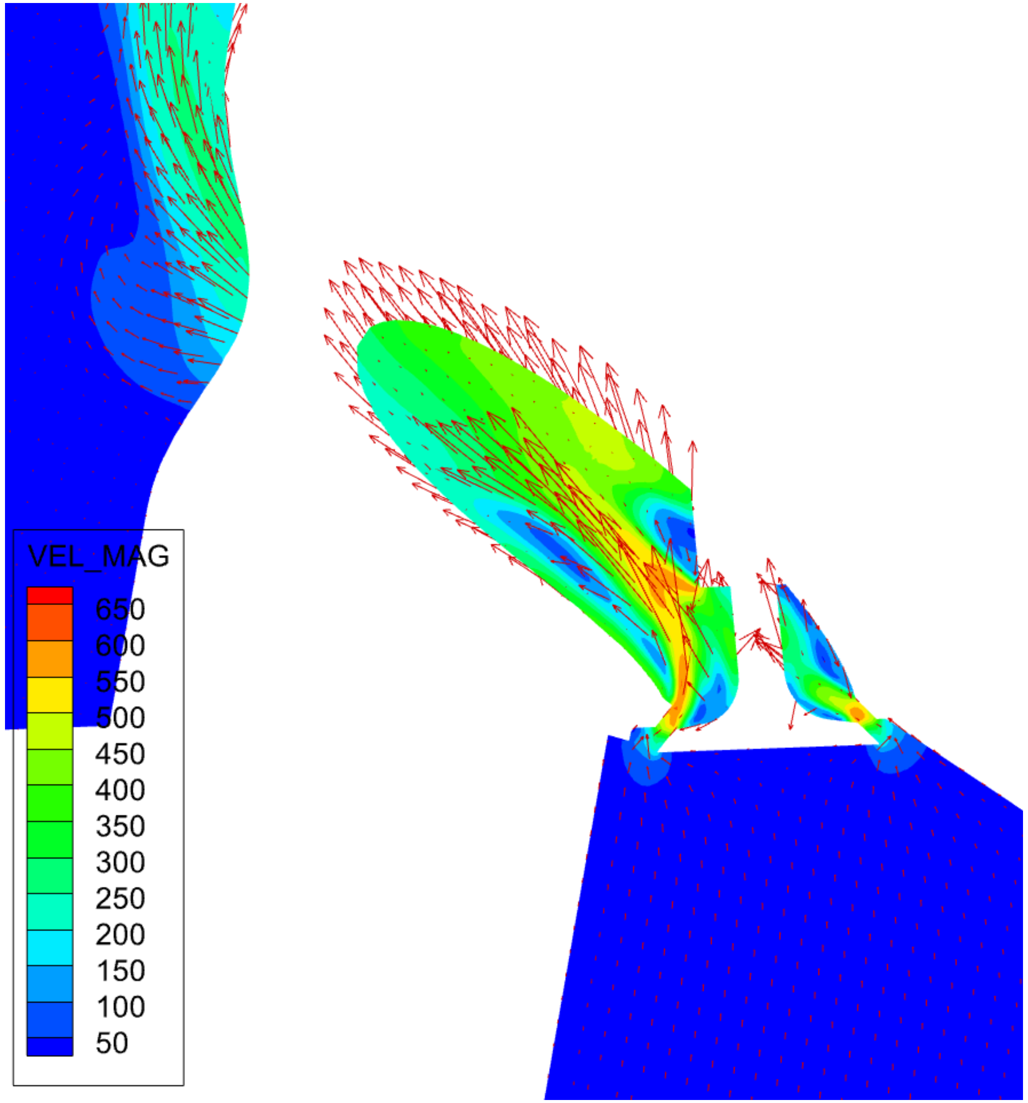


EngSim

Results – Detailed Section Views – Exhaust at 3mm

Section thru valve

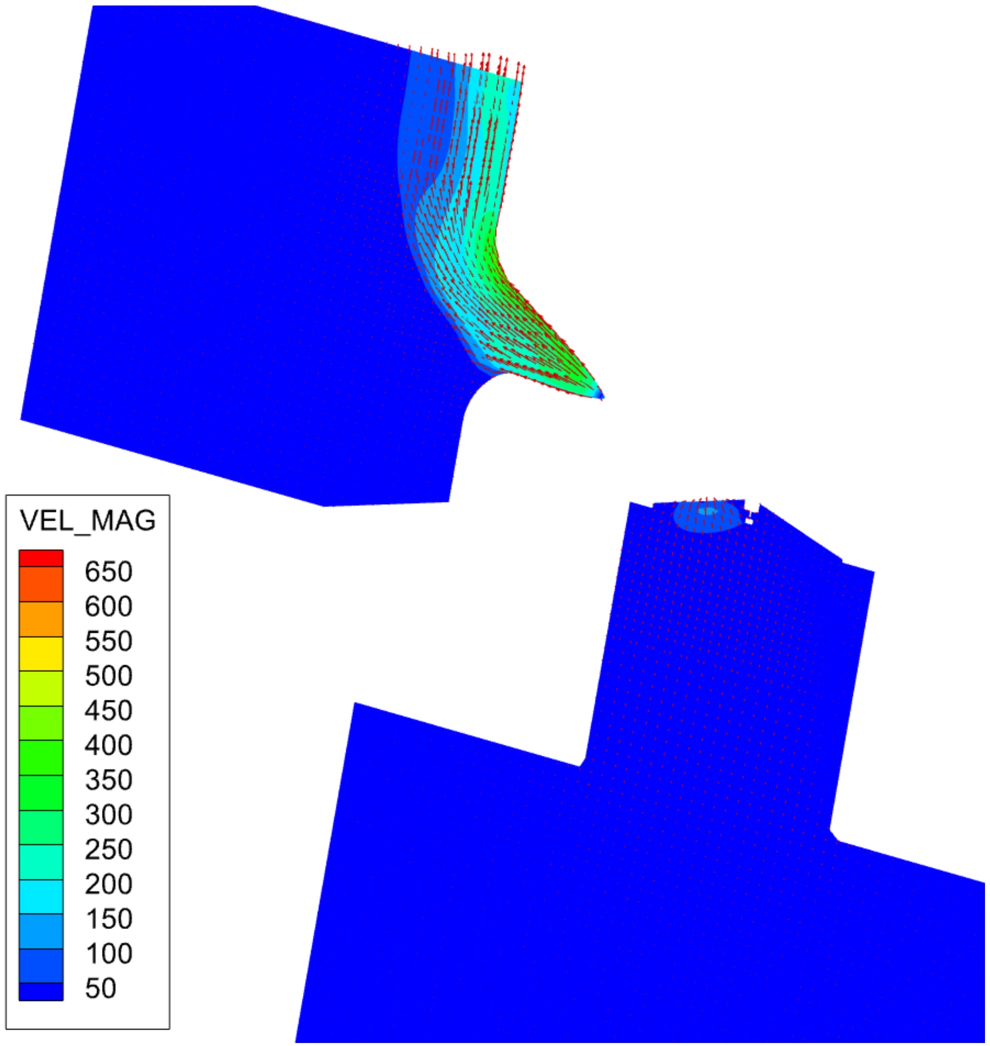


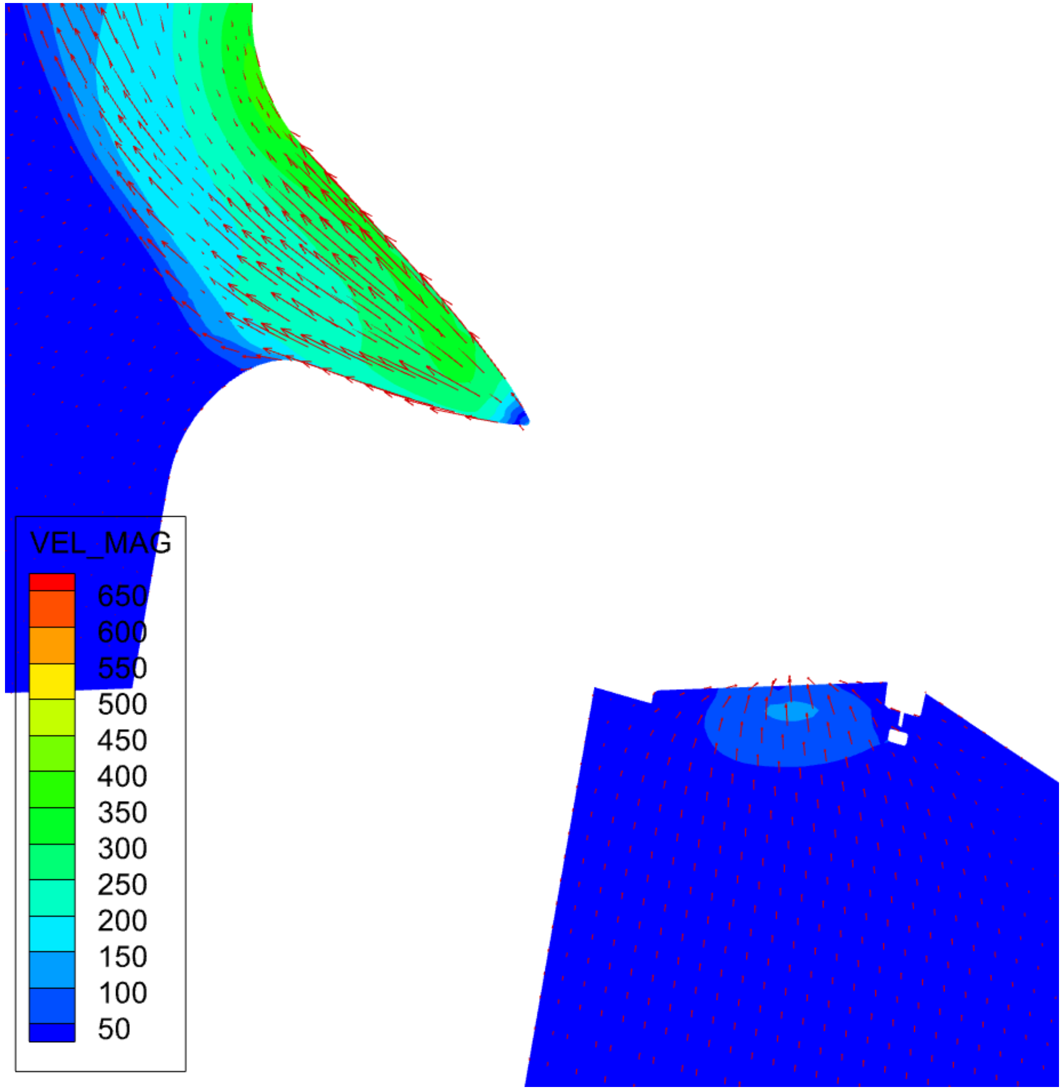


ESEngSim

Results – Detailed Section Views – Exhaust at 3mm

Section thru spark plug





Results – Detailed Section Views – Exhaust 3mm

Horizontal Sections