

KAKINSURANCE

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

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Outline



1. Background

- a. About DDA Engineering 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 DDA Engineering.
- 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.





PERFORMANCE RACING INDUSTRY $\mathbf{2}$



- 1. DDA Engineering 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, DDA Engineering is their "virtual" engineering department for "virtual" engineering/testing.











- 1. Use this project to demonstrate how CFD can support future testing prior to hardware.
 - 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.







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/manifoldetc	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 DDA Engineering 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





- 1. Many CFD software tool choices are available.
- 2. DDA Engineering has been primarily using CONVERGE.
- 3. CONVERGE is an industry leader for <u>predictive</u> engine and incylinder flow and combustion with moving meshes.











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...





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







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.







Port Flow Project – Setup and Cases Studied, Intake



- 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





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	-	-	-









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EDUCATION









Horizontal Sections







Section thru valve















Horizontal Sections













Section thru 3mm valve









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Horizontal Sections





Results – Detailed Section Views – Exhaust at 3mm











Results – Detailed Section Views – Exhaust at 3mm







Results – Detailed Section Views – Exhaust 3mm







Results – Detailed Section Views – Exhaust at 6mm









Results – Detailed Section Views – Exhaust at 6mm









Results – Detailed Section Views – Exhaust 6mm







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.
- Add in manifolds to transient modeling to see cylinder-to-cylinder effects – usually very enlightening.

Full Moving Piston/Valves Transient with Combustion







Temperature (K)

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.







- 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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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





















Horizontal Sections



Results – Detailed Section Views – Exhaust at 3mm









Results – Detailed Section Views – Exhaust at 3mm







Results – Detailed Section Views – Exhaust 3mm





