Optimizing Intake Manifold Geometry for Mass Flow Rate Enhancement in a 2005 Yamaha YZF-R6 Engine: A CFD-Driven Analysis

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NIU HUSKIE MOTORSPORTS

Introduction

- Internal combustion engines function by converting chemical energy to mechanical energy by combusting fuel mixed with atmospheric air. An engine's power increases with its ability to flow more air and fuel.
- The delivery characteristics of this air and fuel mixture are affected primarily by a component called the intake manifold Fig.(1).
- This study aims to characterize how the geometry of key components within the intake manifold effect engine power.
- Runner length Fig.(2.1, 4), plenum volume Fig.(2.2, 5), runner opening area Fig.(2.3, 6), runner opening radius Fig.(2.4, 7), runner inset distance Fig.(2.5, 8), and throttle body size Fig.(2.6, 9) were determined to be potentially impactful design parameters to intake manifold performance.

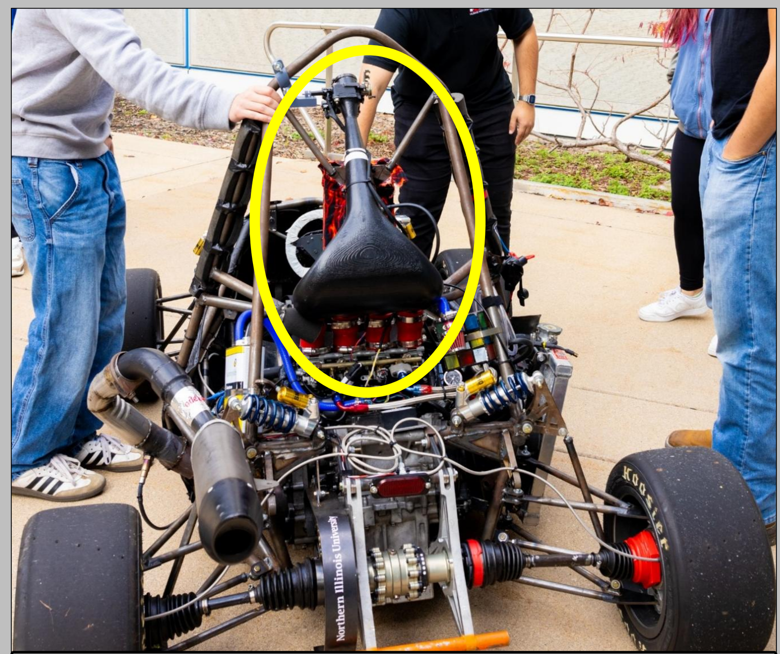


Fig.(1) – Intake Manifold Location

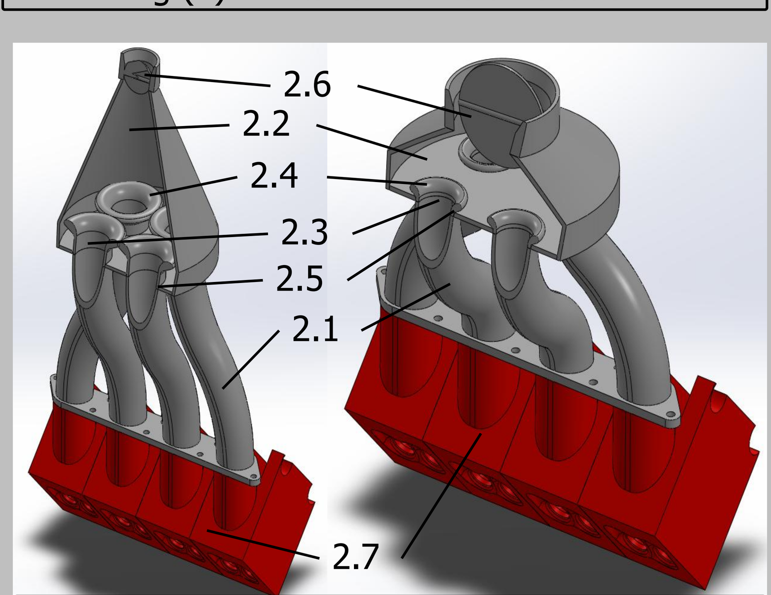


Fig.(2) – Intake Parameters and Variation, Engine Head

Objective

This study aims to characterize the relationship between intake manifold geometry and the performance of a simulated 2005 Yamaha YZF-R6 engine. The relationships were elucidated through computational fluid dynamics (CFD) simulations and used to optimize the performance of the intake manifold and engine. This study also provides insights for optimization strategies by investigating design parameter independence and performance characteristics within the intake manifold system.

Application

The intake manifold designed in this study is expected to be implemented on Huskie Motorsports' 2025 competition car. Huskie Motorsports is NIU's Formula SAE (FSAE) team. FSAE is a competition that is sanctioned by the Society of Automotive Engineers where colleges from around the world design, build, and race formula-style open wheel racecars. This intake manifold is designed to improve engine performance from an intake manifold implemented on Huskie Motorsports' 2024 competition car.

Equation Variables

V = Engine Volume
$\dot{V}$ = Volumetric Flowrate
ω = Peak Engine Power RPM
D_a = Valve Angular Duration
D_t = Valve Time Duration
P = Engine Power
$\dot{m}$ = Mass Flowrate
n_c = # of Cylinders
t_c = Valve Close Time
t_o = Valve Open Time
λ = Air/Fuel Ratio
e = Fuel Specific Energy
η_T = Thermal Efficiency

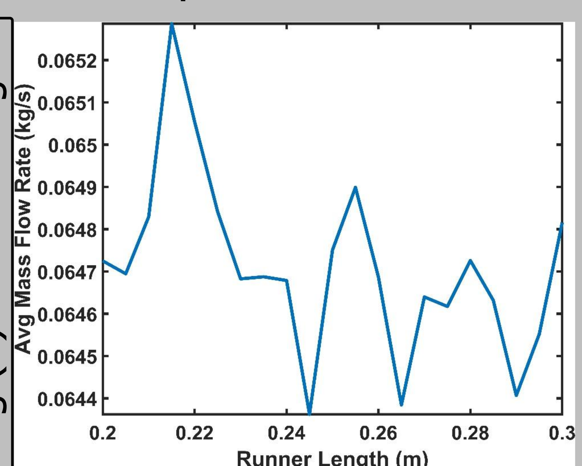
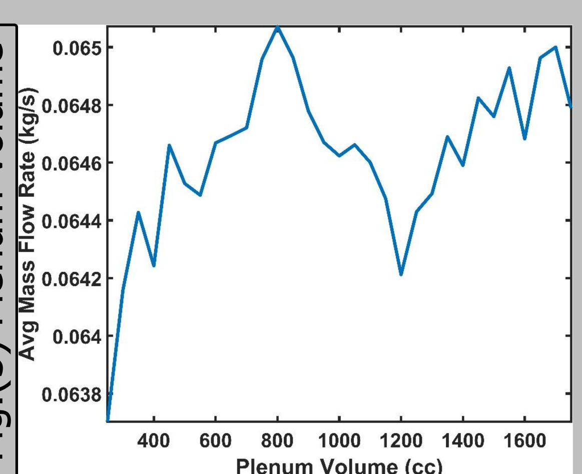
Fig.(4) Runner Length


Fig.(5) Plenum Volume


Methodology

- ***PipeMax Professional Engine and Header Design*** was used to find baseline values for each design parameter.
- The "Conical Center Feed" design was selected as prior research has demonstrated it provides the most uniform air distribution[1].
- Upper and lower test bounds were developed for each design parameter. Step increments were developed to split the range into 20-30 test values / design points.
- Using ***SolidWorks,*** a model of the engine head Fig.(2.7), and a parametric model of the intake manifold were created and mated in an assembly. A hollow sphere was mated to the top of the intake manifold to simulate atmospheric conditions.
- Using Eq.(1), the average volumetric flowrate of the engine was found.
- Using Eq.(2), each intake valve's open delay and open duration (in seconds) was determined.
- In ***SolidWorks Flow Simulation*** Fig.(3), multiple parametric, transient, internal flow studies were created to analyze one design parameter at a time.
- An atmospheric boundary condition was set in the hollow sphere. Volumetric flowrate boundary conditions were set where the air enters the engine, at each intake port. The flowrate was set to the rate found with Eq.(1). The flow was set to a duration equal to the valve open time found with Eq.(2), after a delay equal to the one also found with Eq.(2). These flow conditions were set to repeat periodically.
- A time step was chosen of (Valve open duration)/100, and the simulation runtime was set to allow cylinder 2 to complete eight open/close cycles.
- A mass flowrate goal was set at the cylinder 2 intake port boundary.
- The mass flowrate goal data was exported to a ***MATLAB*** script. The script averaged and plotted the performance data from only the specified "on" times for cylinder 2 Fig.(4-9).
- A final test was conducted comparing an intake manifold assigned the optimal design parameter values from each parametric study Fig.(10 – Design Point 3), an intake manifold assigned the baseline values Fig.(10 – Design Point 2), and an intake manifold that was assigned identical parameter values to the 2024 intake manifold, but in the Conical Center Feed style Fig.(10 – Design Point 1).

Eq.(1)
$$\dot{V} = \frac{V \cdot \omega}{60 \cdot 2}$$

Eq.(2)
$$D_t = \frac{D_a}{360 \cdot \omega} \cdot 60$$

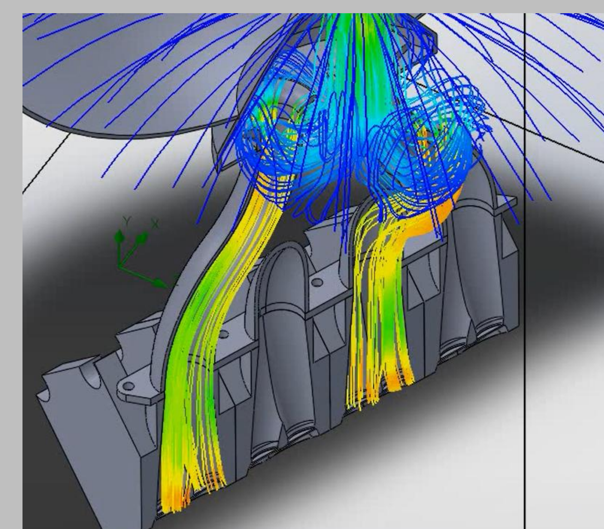


Fig.(3) Flow Test Visualization

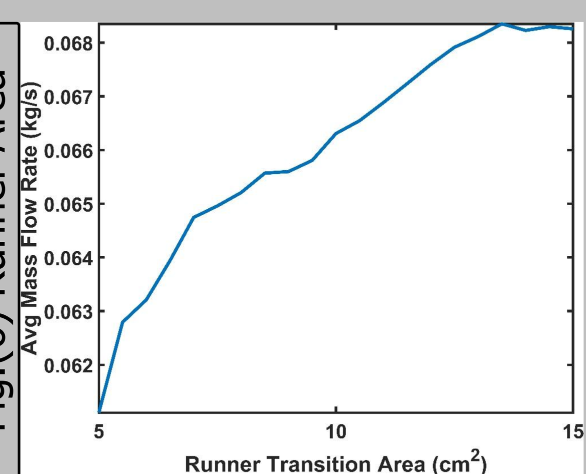
Fig.(6) Runner Area


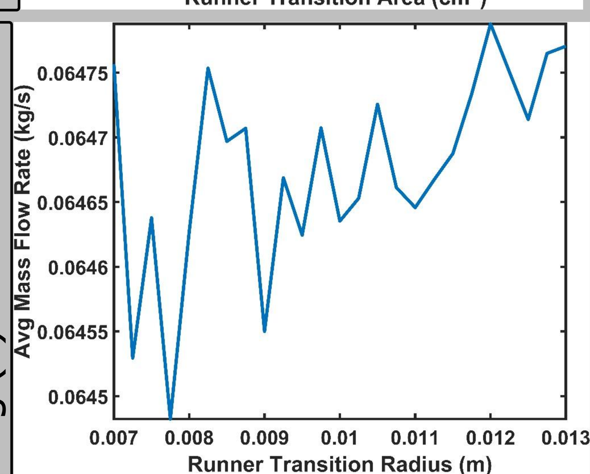
Fig.(7) Runner Radius


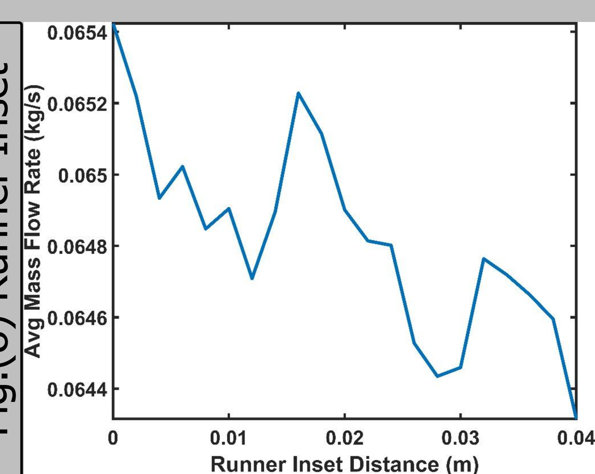
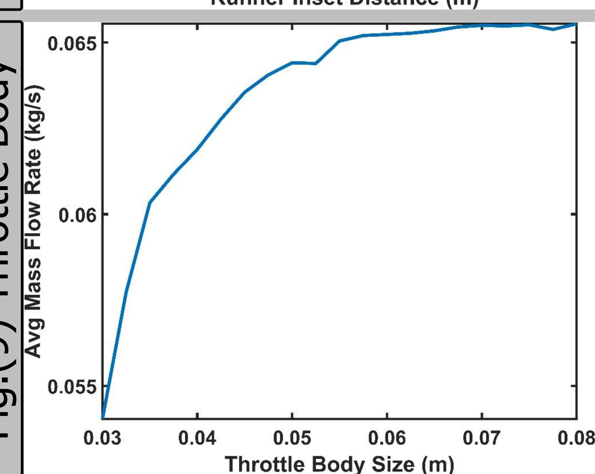
Fig.(8) Runner Inset


Fig.(9) Throttle Body


Conclusion

This study proves that intake manifold performance can be substantially improved by isolating, testing, and combining optimal design parameter values. Measurable improvements in mass flowrate and engine power output were found. The previous intake manifold was created by observing designs developed by other FSAE teams; no CFD validation was performed. Using Eq.(3), the optimized intake manifold developed through this research had a calculated power output of 87.2 kW (116.9 horsepower). Compared to the 2024 intake manifold that had a calculated power output of 77.0 kW (103.3 horsepower). This difference in power output represents a 12% increase in performance over the 2024 intake manifold. Increased power results in increased acceleration and increased top speed, which are key factors in achieving faster lap times and competitive success.

Eq.(3)
$$P = n_c \cdot \frac{\frac{\dot{m}(t_c - t_o)}{\lambda} \cdot e \cdot \omega}{60 \cdot 2} \cdot \eta_T$$

This study also shows that each design parameter value has limited effect on other design parameters' performance. The performance of the optimized intake manifold exceeds the performance observed from any single design parameter study. This means that single design parameter optimization can be used when designing an intake manifold, and design parameter interplay can be disregarded.

Future Work

A comparison of the optimized, baseline, and previous intake manifold should be made in actual implementation. This will verify the accuracy of the CFD analysis. In future, this methodology should also be applied to other engine platforms with different performance characteristics. This methodology was designed to be applicable to any optimization process within ***SolidWorks Flow Simulation***, with the potential to be extended to other car components such as the nosecone, aerodynamics package, and radiator cowling.

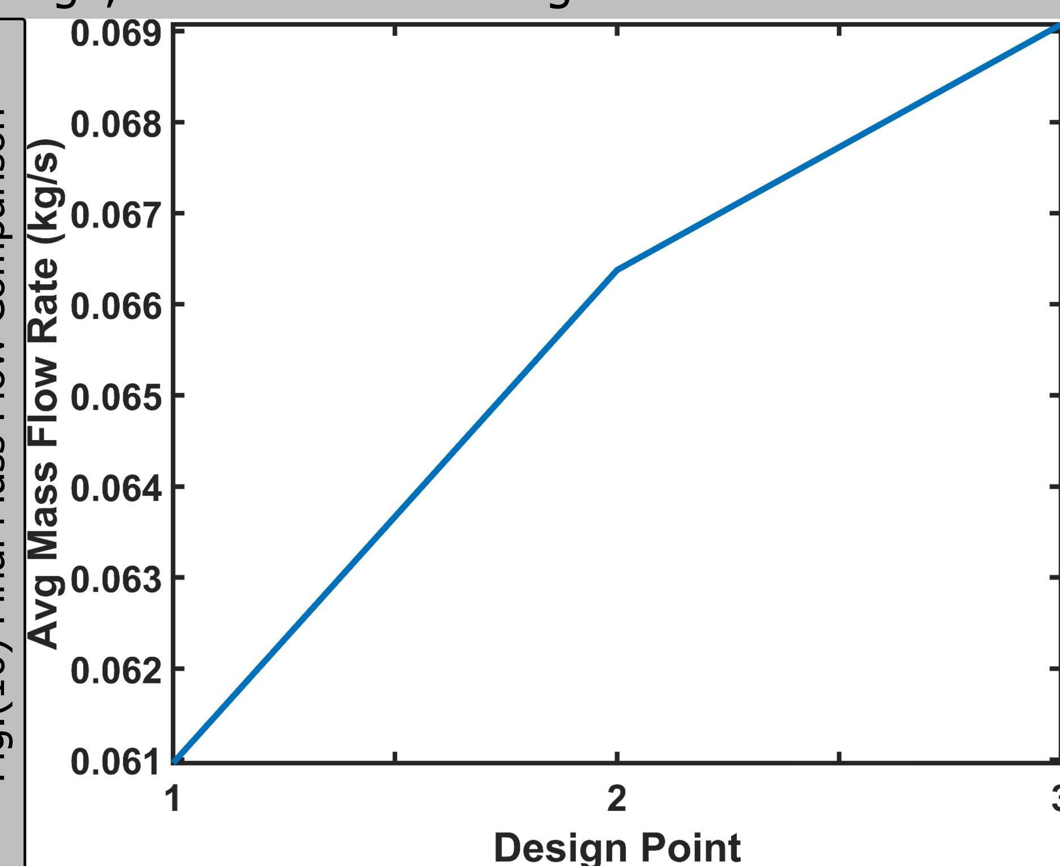
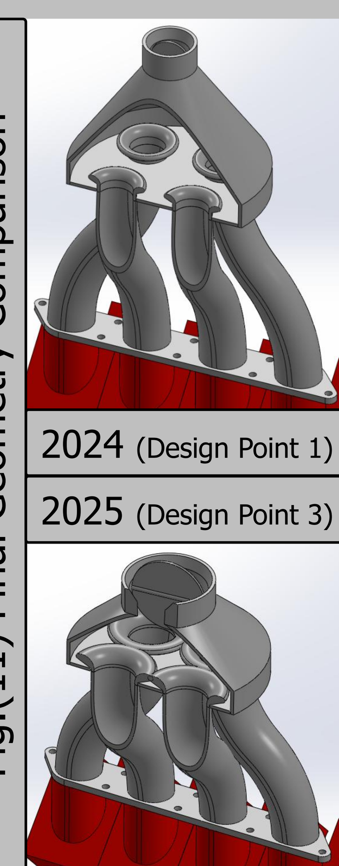
Fig.(10) Final Mass Flow Comparison


Fig.(11) Final Geometry Comparison


Acknowledgements

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References

[1] Claywell Mark R, Horkheimer, D., & Stockburger, G. (2006). Investigation of Intake Concepts for a Formula SAE Four-Cylinder Engine Using 1D/3D (Ricardo WAVE-VECTIS) Coupled Modeling Techniques. Motorsports Engineering Conference & Exposition. https://doi.org/10.4271/2006-01-3652

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