Track Based Fuel and Lap Time Engine Optimization

ESTECO Academy
Design Competition 2016/2017

In partnership with:

APRILIA RACING & GTI Software

aprilia® racing

University of Idaho
College of Engineering

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Project Objective

Racing is about being the **fastest** or having the shortest time; many races also involve **energy management** strategies.

Our objective is to give Aprilia a track-based model to manage lap time and fuel usage.

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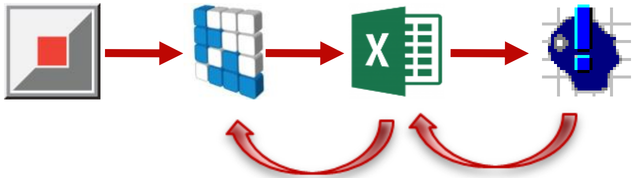

- Results (Torque and BSFC Curves)
- Conclusions (Optimized Engine)
- References
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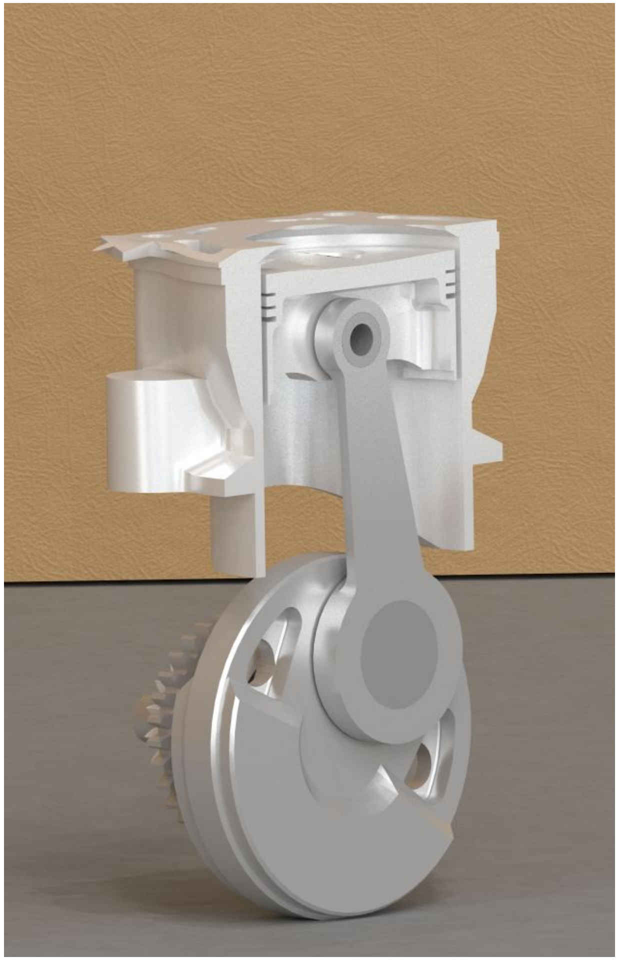
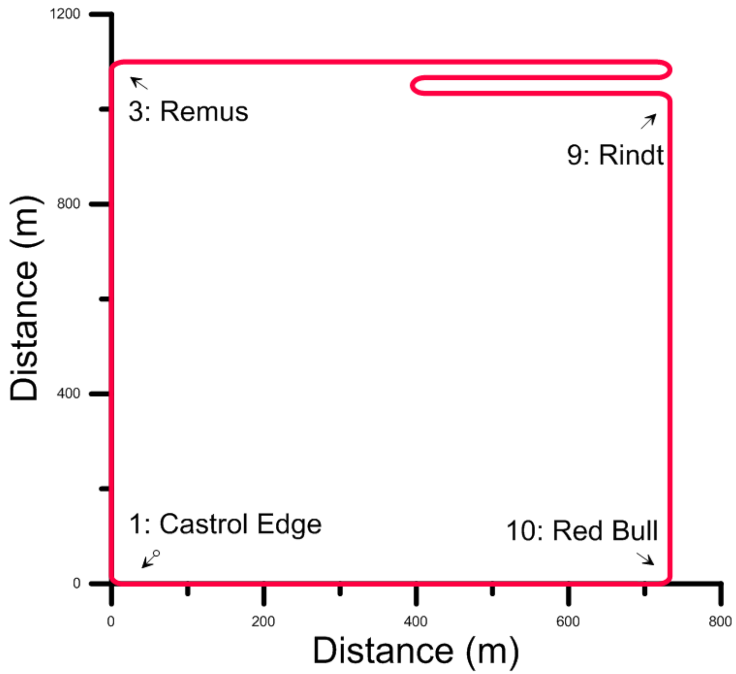
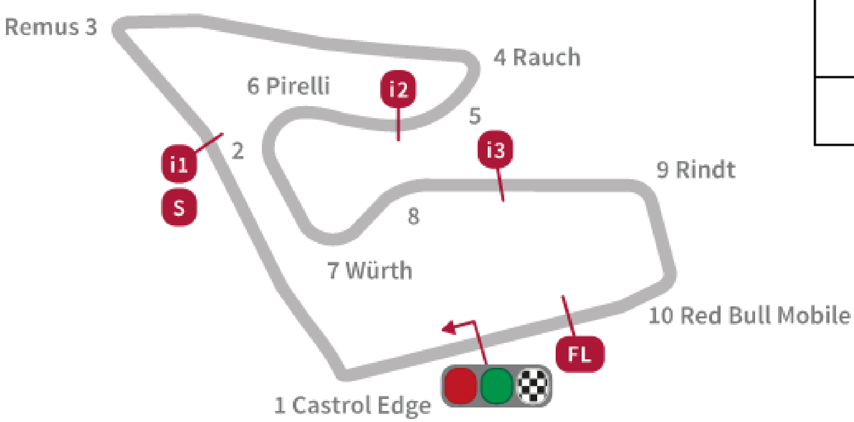


Simulated Test Track [1] VS. Austrian Grand Prix



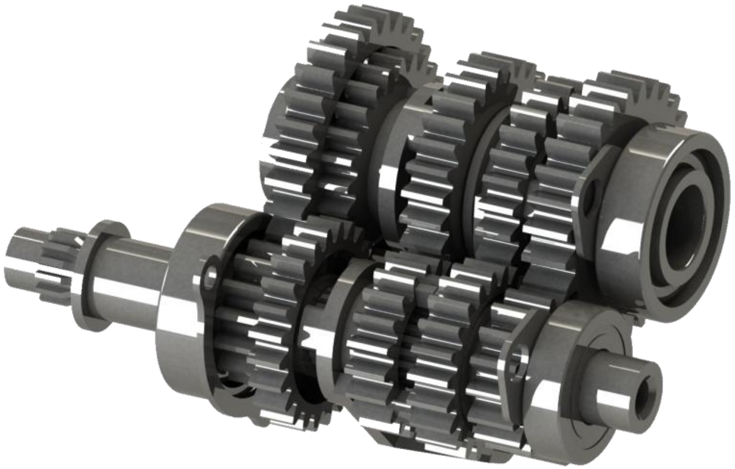


	Simulated Test Track	Austrian Grand Prix
Length	4.3 km	4.31 km
Max Velocity	210 km/h	219 km/h
# of Major Turns	6	6
# of Straights	6	6
Longest Straight	1066 Meters	626 Meters
Lap Time	102 Seconds	96.228 Seconds

University of Idaho TK Solver Track Simulation

- This track simulation program supported the University of Idaho 2014 Formula Hybrid team. [2]
  - 1st Place Overall
  - Chrysler Powertrain Award
  - General Motors Design Award
- TK Solver program interfaced with modeFRONTIER via Microsoft Excel

Simulated Motorcycle Specifications



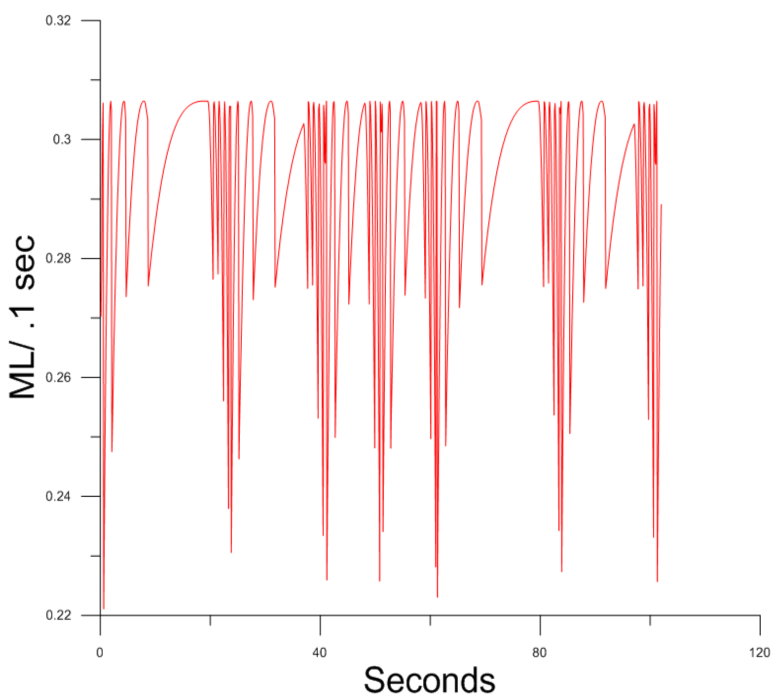
Bike Specs	Gear Ratios

- Weight: 147 Kg
- Tire Diameter: 58.4 cm
- CD: 0.62
- FA: 0.3 m^2

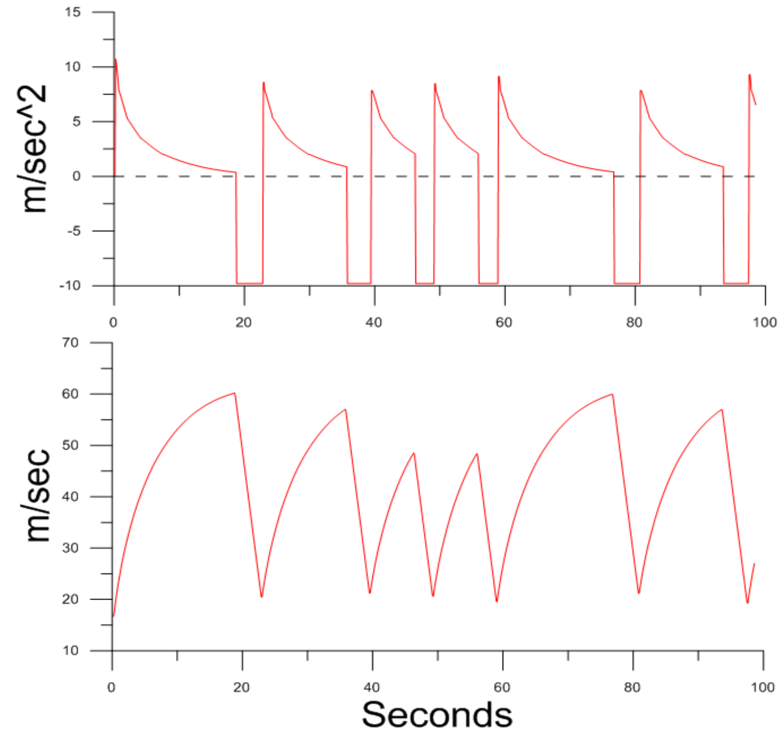
1nd: 2.7692
2rd: 1.9412
3th: 1.45
4th: 1.1739
5th: 0.96
Primary Reduction: 2.952
Final Reduction: 2.4

Track Simulation Output (Fastest Lap)

Instantaneous Fuel Consumed



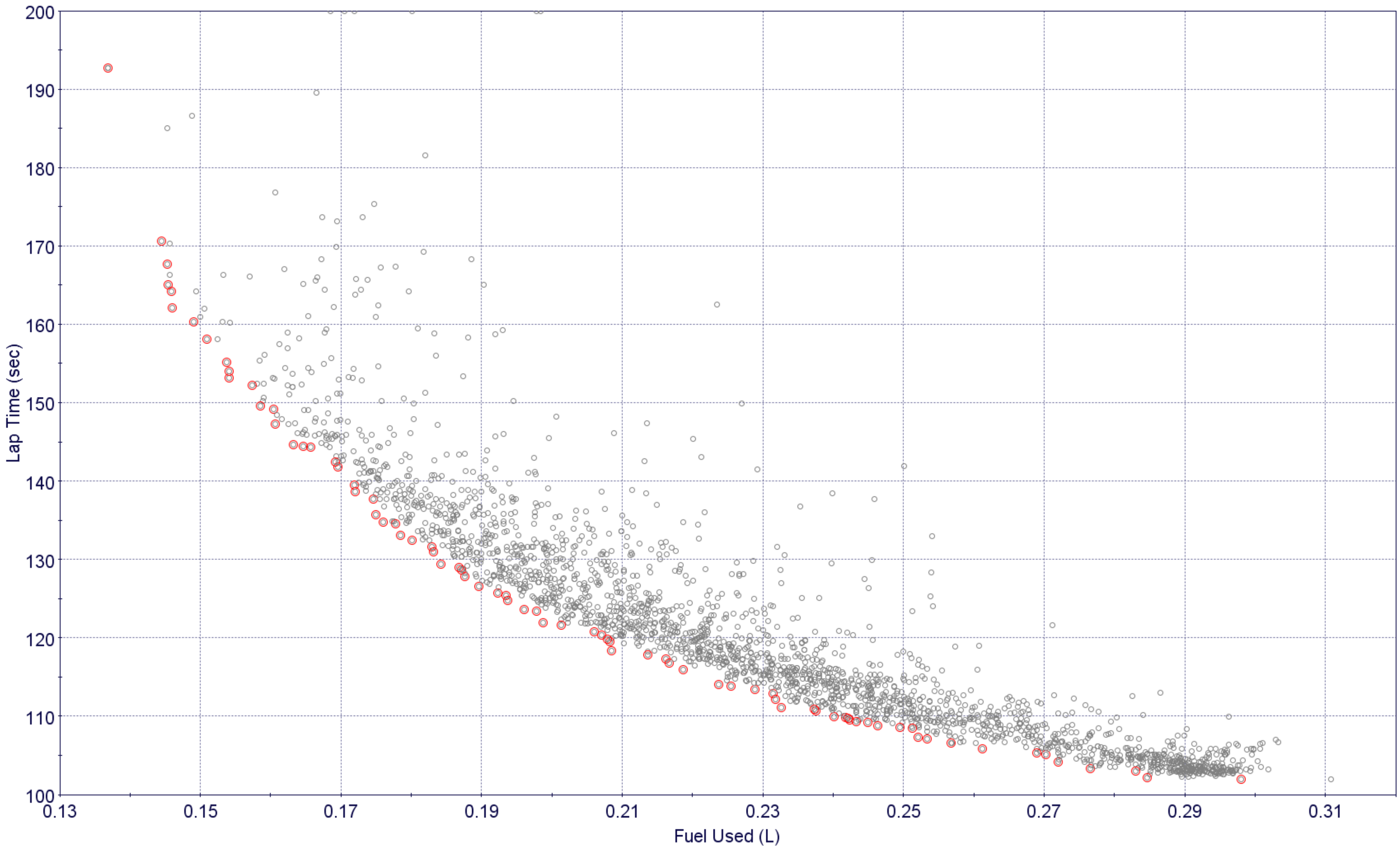
Acceleration and Velocity



Total Fuel Used: 0.298L

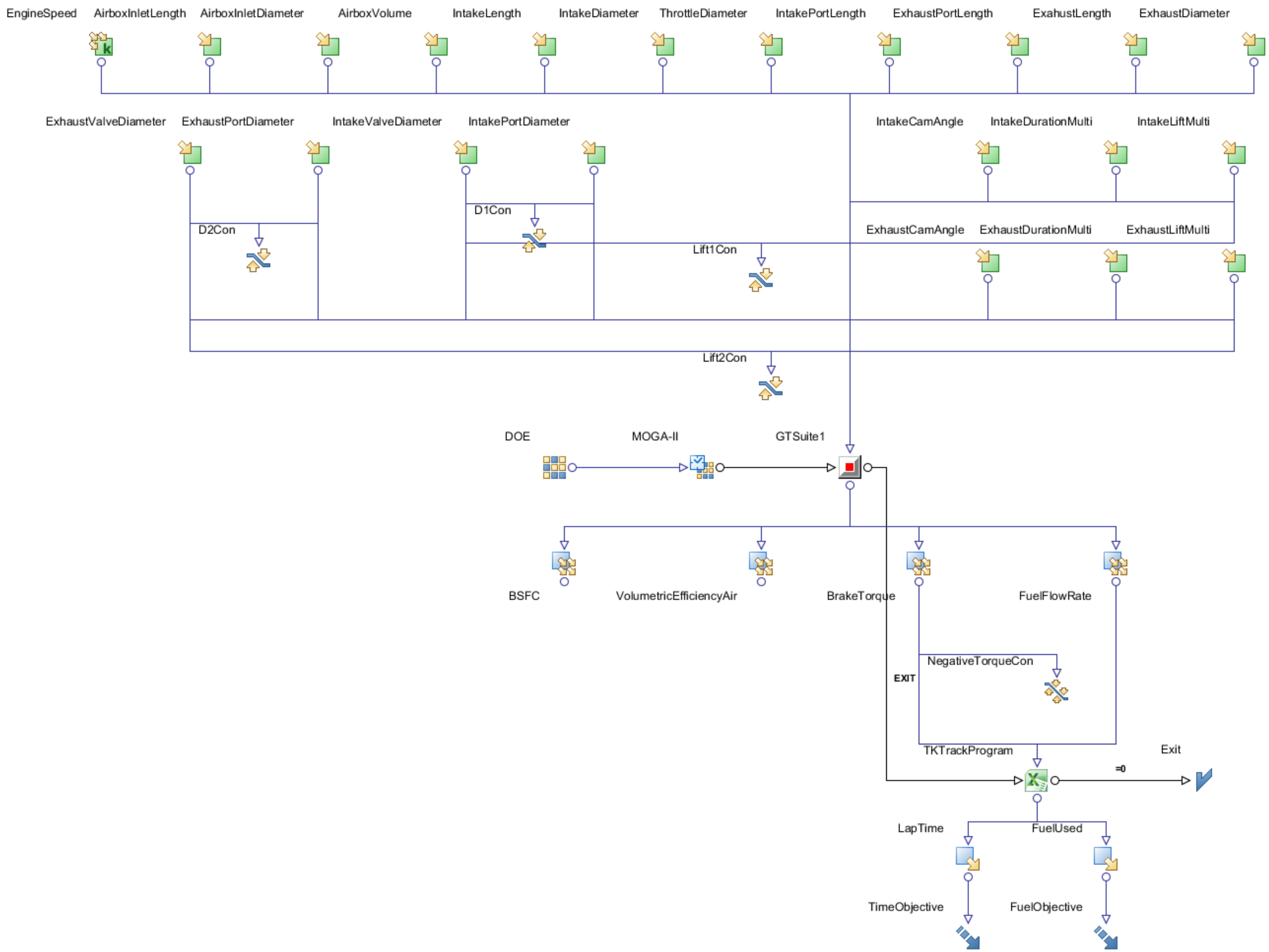
Lap Time: 102 Seconds

Pareto Front: Lap Time vs. Fuel Usage



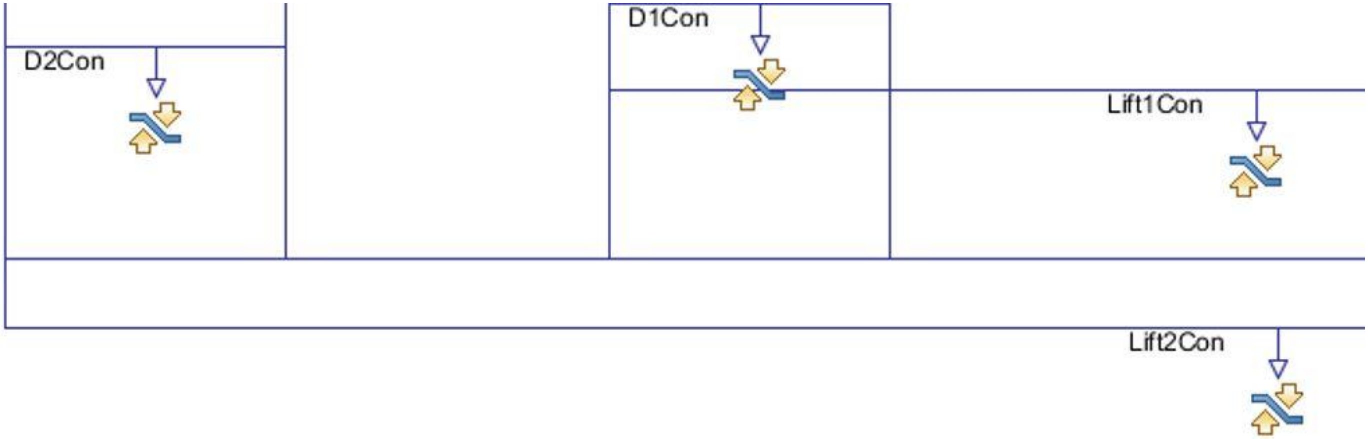
Integration of Engineering Solvers

modeFRONTIER + GT-SUITE + Excel + TKSolver

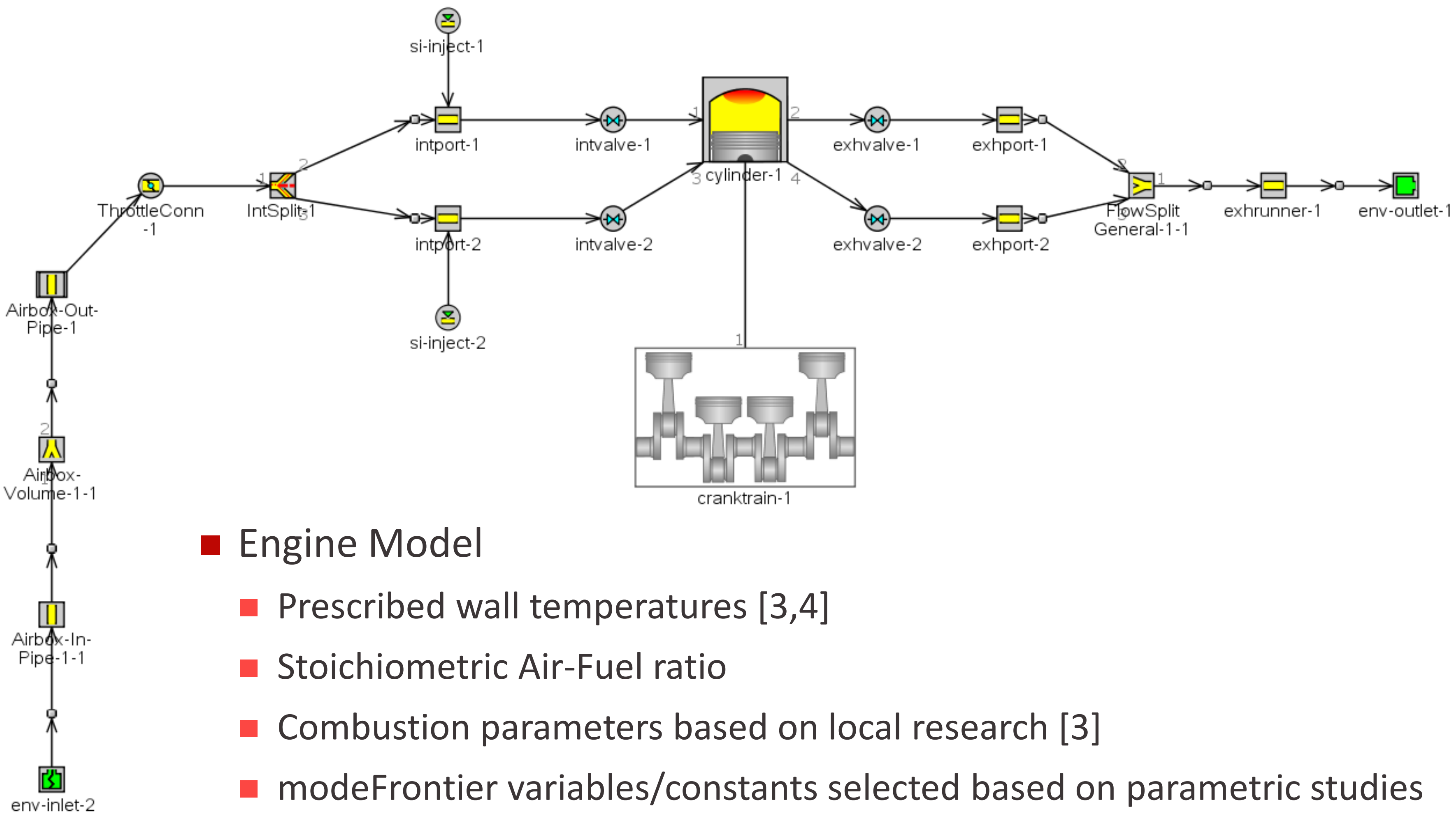


modeFRONTIER Constraints

- Variables Constrained to increase numerical stability
  - Intake/Exhaust Cam Lift Multiplier
  - Intake/Exhaust Port Diameter
  - Engine Output Torque
- Reasons for constraints
  - Limit intake and exhaust flow relations to the flow correlation table range
  - Minimum torque constraint required for proper shifting in TK program



GT Model

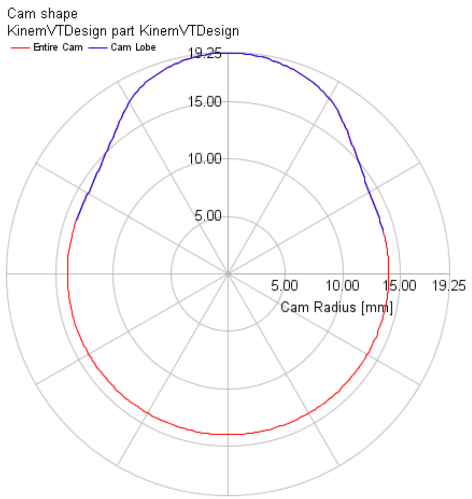


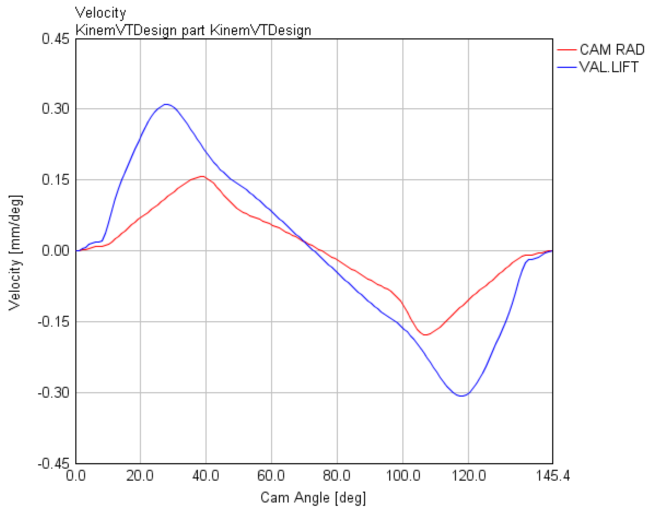
- Engine Model
  - Prescribed wall temperatures [3,4]
  - Stoichiometric Air-Fuel ratio
  - Combustion parameters based on local research [3]
  - modeFrontier variables/constants selected based on parametric studies

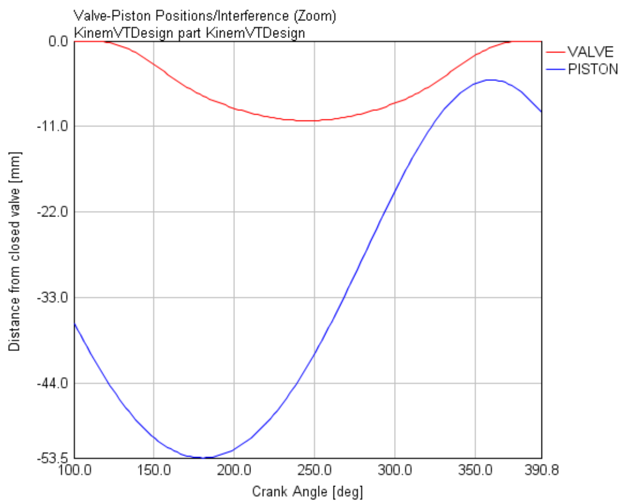
GT Intake/Exhaust

- Intake
  - Modeled as two pipes with Air Box simplified as a flow split volume [5]
  - Air filter losses neglected as suggested by GT-POWER manual
  - Throttle located directly in front of cylinder head ports
  - Only WOT condition considered due to racing application
  - All lengths, diameters, and volumes are variables
- Exhaust
  - Modeled as simple pipe
  - Length and diameter variables
- Ports
  - Modeled as flow splits followed by individual pipes for ports
  - Length and diameter variable with flow split volumes calculated from port geometry

GT Valve





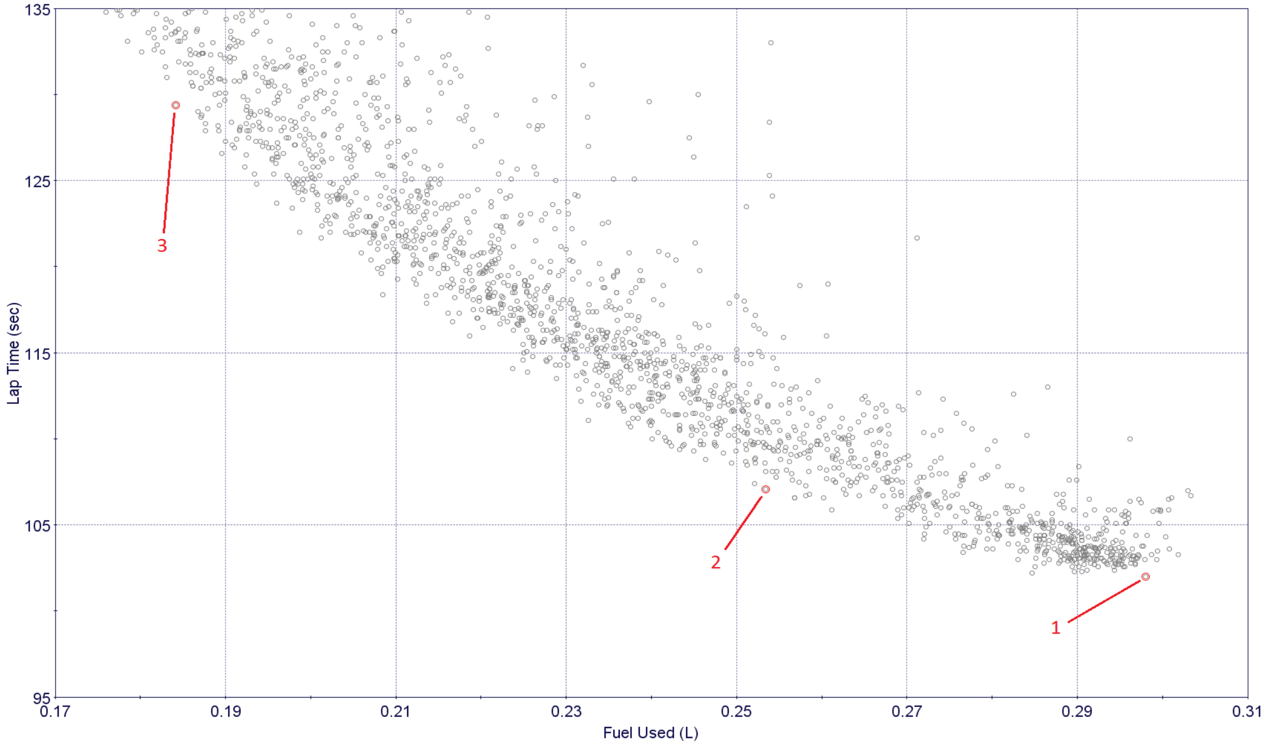


- Base radius sized to minimize contact stress
- Profile designed to minimize concavity, allowing manufacturability
- Lift values transferred to valve nodes in engine model [6,7]

- Valve velocity limited to reduce inertial loading
- Ramp velocities minimized to ensure follower contact at high RPM

- Valve piston interference calculated
- Full interference design chosen to maximize compression ratio

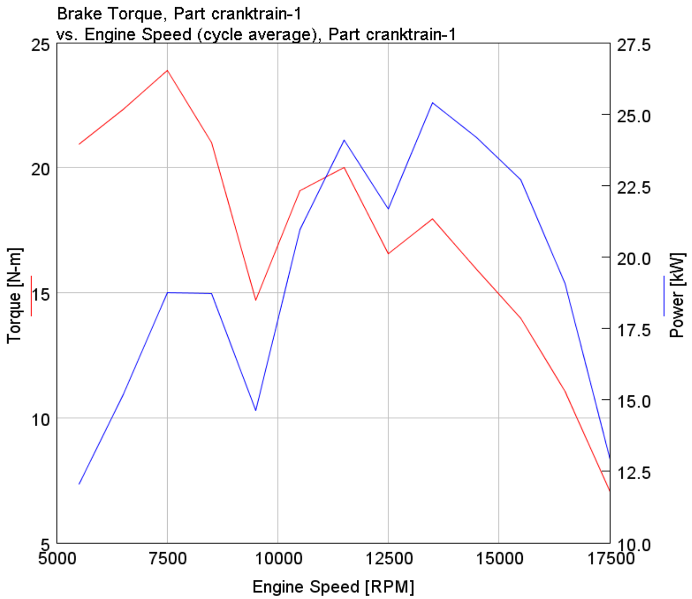
Results

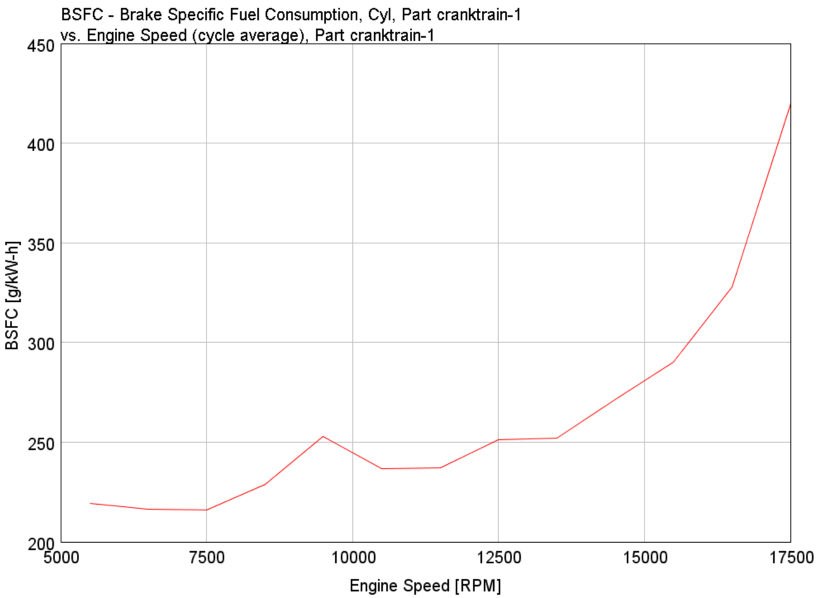


Case Number	Max Torque and RPM	Fuel Consumption (LIters)	Lap Time (sec)
1	23.4 Nm at 11500 RPM	0.298	102.0
2	23.9 Nm at 7500 RPM	0.253	107.1
3	15.8 Nm at 5500 RPM	0.184	129.4

Results: Case 2 (75% Lap Time and 25% Fuel Usage)

- GT outputs along with track data show that this is a good configuration
- Design power curve shows maximum output in the 11000-15000 RPM range, the operating range for our gearing configuration.
- Some lengths in this configuration are not practical due to motorcycle packaging reasons





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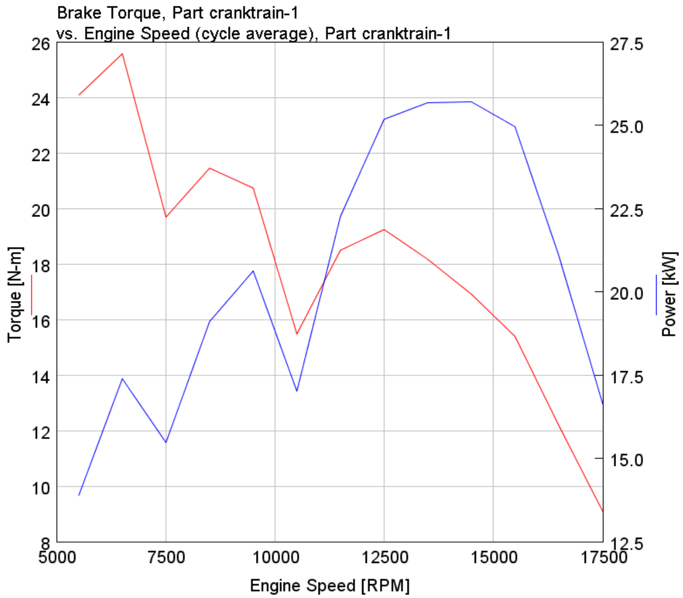
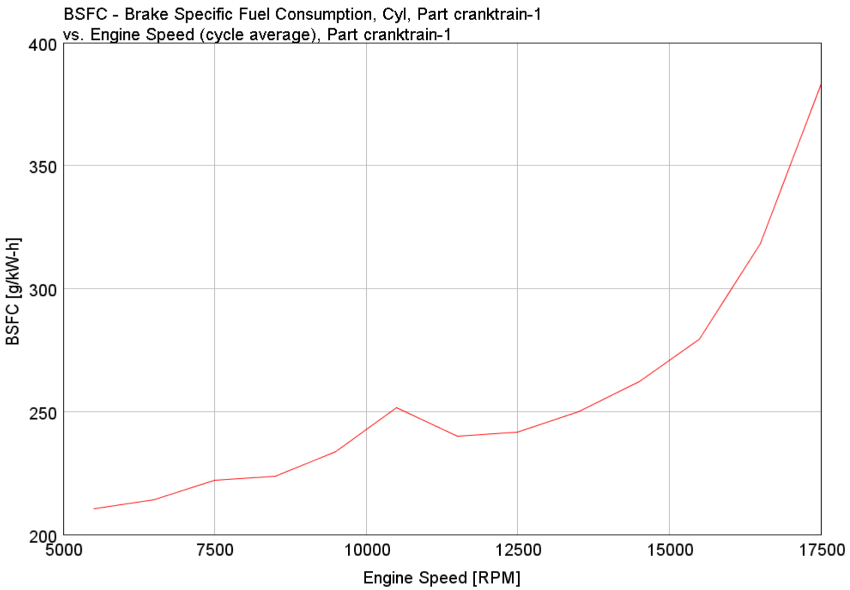
Results: Case 2 “Making it Fit”

- Revisions made to Case 2 in order to improve **packaging** and **manufacturing**
  - Doubling of intake air box resonant frequency
  - Doubling of exhaust tuned frequency
  - Rounding of all dimensions to nearest tenth of degree or millimeter
- As can be seen below output improved in desired operating range without a loss in fuel efficiency
- Ramming peaks and troughs due to acoustical effects are shifted slightly due to more complex interactions, but effect is beneficial in intended range





Conclusion

- Final Design Specs
  - Air box
    - Inlet Diameter = 68 mm
    - Inlet Length = 469 mm
    - Volume = 2.66 L
  - Intake
    - Length = 428 mm
    - Diameter = 60 mm
    - Throttle Diameter = 47 mm
    - Port Diameter = 49 mm
    - Port Length = 90 mm
    - Valve Diameter = 34.1 mm
  - Cam
    - Intake
      - Duration = 257.7 crank degrees
      - Lift = 7.5 mm
      - Angle = 327.4 crank degrees
    - Exhaust
      - Duration = 298.0 crank degrees
      - Lift = 8.0 mm
      - Angle = 103.1 crank degrees
  - Exhaust
    - Length = 698 mm
    - Diameter = 51 mm
    - Port Diameter = 29.5 mm
    - Port Length = 105 mm
    - Valve Diameter = 27.4 mm

- Further revisions of this design would be needed before production, but the general concept behind the track coupling to modeFRONTIER as a method of optimization has shown to be effective
- Optimizations of individual parameters could now be performed in order to further improve existing design, or to develop new features such as variable intake length or volume controls
- Minor features such as air filter restriction, or more accurate heat transfer models could also be implemented to improve model accuracy

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1) Butsick, Brandon P. “Design and mathematical modeling of a hybrid FSAE drivetrain.” Thesis. University of Idaho, May 2011. Print.
2) Lilley, Rory M. "Development and Calibration of the Internal Combustion Engine used in the University of Idaho Hybrid Vehicle Powertrain." Thesis. University of Idaho, August 2016. Print.
3) Cuddihy, Jeremy L. "A User-Friendly, Two-Zone Heat Release Model for Predicting Spark-Ignition Engine Performance and Emissions." Thesis. University of Idaho, May 2014. Print.
4) Blair, Gordon P. Design and simulation of four-stroke engines. Warrendale: Society of Automotive Engineers, 1999. Print.
5) Montenegro, G., Cerri, T., Della Torre, A., Onorati, A. et al., "Fluid Dynamic Optimization of a Moto3^{TM} Engine by Means of 1D and 1D-3D Simulations," *SAE Int. J. Engines* 9(1):588-600, 2016, doi:10.4271/2016-01-0570.
6) GT Valve Manual, Gamma Technologies GT-Suite
7) Wang, H., Nitu, B., Sandhu, J., Zhong, L. et al., "Integrated Engine Performance and Valvetrain Dynamics Simulation," SAE Technical Paper 2016-01-0483, 2016, doi:10.4271/2016-01-0483.

About the Team

Left to Right: Bill Duncan, Brian Remsen, David Pick II, Dylan Johann
Not Pictured: James Founds (Mentor)

The four members of the team have 25 years of combined interest (one member started at the age of 11) in engine repair and race engine building. All members are seniors in the Mechanical Engineering department at the University of Idaho. We appreciate this opportunity to explore new analytical tools and optimization methods of engine design.

Thank you for your attention!