University of Maine

Formula SAE 2011-2012
Engine Design Report

Abstract

Formula SAE is an international design competition held annually by the Society of Automotive Engineers. The University of Maine has prepared a Formula style car featuring a chromoly space frame, an V-Twin engine, fully independent double wishbone suspension, composite driver’s seat, and a Torsen differential.
Acknowledgements

The development and assembly of UMaine’s Formula SAE car has been considerably supplemented by sponsorship and volunteering help. We would like to thank our sponsors: University of Maine, Milton Cat, Maine Air National Guard, Western Racing Developments, Thayer’s Automotive, Fiber Materials, Glidden Auto Body, Custom Composite Technologies, Lotus, Solidworks, PTC, and Autodesk.

We would also like to thank the Caribou Technical School for welding many of our components, and Noland Trans-world Cycle for resealing our engine so quickly and providing us with much useful Aprilia advice.

Special thanks to Murray Callaway for all of his help in creating this document, Luke Saindon for taking the initiative to start this team, Karen Fogarty for placing all of our parts orders for the past three years, Diane Maguire for her guidance with the production aspect of our design, and Mick Peterson for leading the Capstone design program.

Table of Contents

University of Maine .............................................................................................................. 1
Abstract .................................................................................................................................. 1
Acknowledgements ................................................................................................................. 2
Table of Figures ....................................................................................................................... 3
Table of Graphs ....................................................................................................................... 3
Table of Figures....................................................................................................................... Error! Bookmark not defined.
Table of Photos....................................................................................................................... 3
1.0 Introduction ....................................................................................................................... 4
  1.1 2012 University of Maine Formula SAE Car ................................................................. 4
  1.2 Team Background ......................................................................................................... 4
3.0 Aprilia RXV 550 ............................................................................................................. 5
  3.1 Selection Criteria .......................................................................................................... 5
  3.2 Design Goals and Development Process .................................................................... 6
    3.2.1 Lotus Engine Simulation ....................................................................................... 6
    3.2.2 Intake .................................................................................................................... 8
    3.2.3 Exhaust .................................................................................................................. 11
    3.2.4 Engine Mounting ................................................................................................. 12
    3.2.5 Engine to Chassis Integration ............................................................................. 13
    3.2.6 Fuel Tank............................................................................................................... 13
    3.2.7 Data Acquisition .................................................................................................. 15
    3.2.8 Tuning ................................................................................................................... 16
    3.2.9 Cooling .................................................................................................................. 17
    3.2.10 Lubrication ........................................................................................................... 18
    3.2.11 Engine Conclusion ............................................................................................... 18
References ................................................................................................................................ 19
Table of Figures

Figure 13: Stock Aprilia RXV 550 wiring diagram ................................................................. 13
Figure 14: Aluminum fuel tank, approximate volume of 2.1 liters ........................................... 14
Figure 15: Inner fuel tank baffles prevent fuel from splashing while the car is being driven .......... 14
Figure 16: Data logger wiring diagram ....................................................................................... 16
Figure 17: XV Tuner interface screen ......................................................................................... 17
Figure 18: Stock cooling diagram for Aprilia RXV 550 .............................................................. 17
Figure 19: Aprilia dry sump lubrication system .......................................................................... 18

Table of Graphs

Graph 1: Lotus engine simulation data using stock intake and exhaust designs ...................... 7
Graph 2: Actual graph of stock torque and horsepower curves for an Aprilia RXV 550 .......... 7
Graph 3: Lotus engine simulation data comparing stock and restricted horsepower and torque curves .................................................................................................................. 10

Table of Photos

Photo 1: 2011-2012 University of Maine Formula SAE Team: Corey Demers, Nicholas Grover, Dwight Whitney, Heman Norris, Benjamin Parkin, Stephan Becker, Michael Francis, Nicholas Quatrano, Peter Farnum, and Jacob Morrise... 4
Photo 2: Aprilia RXV 550 on dynomite dynamometer ................................................................. 6
Photo 3: AT Power 28mm throttle body ...................................................................................... 8
Photo 4: Throttle body with air filter .......................................................................................... 9
Photo 5: Solidworks model of fiberglass intake bell mouth ....................................................... 10
Photo 6: Bell mouth fiberglass molding process, using an epoxy based wet vacuum layup .......... 11
Photo 7: The Yoshimura RS-2 muffler has removable packing for easy tuning of the exhaust noise level .................................................................................................................................. 12
Photo 8: Engine located in chassis, set in the rearmost possible position .................................. 13
Photo 9: Race Technology Dash 2 and DL-1 data acquisition system ...................................... 15
Photo 10: Radiators were located on both the left and right sides of the chassis in the original design .................................................................................................................................. 18
1.0 Introduction

1.1 2012 University of Maine Formula SAE Car

For the 2011-2012 season, the University of Maine has designed and built a space frame, open wheel racecar to compete at Michigan International Speedway in May. Highlights of the car include a chromoly space frame, an Aprilia RXV 550 V-Twin engine, fully independent double wishbone suspension, composite driver’s seat, and a Torsen differential. Additionally, elements of the engine have been modified to meet competition rules for intake restriction and exhaust noise levels, the suspension has been developed to maximize performance, and drive train development has focused on weight reduction and longevity. The overall design focus has been simplicity and reduction in parts.

1.2 Team Background

The University of Maine began design work for the Formula SAE competition in the fall of 2009, as part of a continuing senior design class project. Over the first two years of the project, senior capstone groups set up an engine dynamometer and constructed a ventilated enclosure, enabling them to begin engine tuning. At the same time, a group of underclassmen volunteers designed and built the remaining portions of the car, including chassis, suspension, and bodywork.

At the end of the 2010-2011 season, the team had a nearly complete vehicle, but ran into engine issues days before competition. It was decided that it would be more beneficial to withdraw from the competition and instead attend without a car, in order to gain a better understanding of the competition through speaking with other teams and through observing the presentations and dynamic events.

During the 2011-2012 season, a group of ten seniors undertook the job of optimizing the car from the previous season. Assembly of the car as designed by the previous team was completed early in the
season, allowing the team to drive the vehicle and determine what improvements were necessary. After determining the changes needed to create a more competitive vehicle, the team began work on the suspension, engine, and drive train.

### 2.0 Aprilia RXV 550

#### 2.1 Selection Criteria

A 2007 Aprilia RXV 550 engine is providing power for this year’s car. Reducing the weight a racecar is a common design goal throughout the entire racing industry. Reducing weight improves dynamic potential by reducing inertia. The Aprilia RXV 550 engine was chosen because of its exceptionally high power-to-weight ratio, producing 70 HP and weighing just 72 lbs. Additionally, the Aprilia RXV 550 offers high amounts of low-end torque, due to its big bore twin cylinder design. Therefore, this engine is ideal for the driving characteristics that will be experienced at the Formula SAE competition. The small footprint of the engine allows for flexibility when mounting it in the chassis.

A complete donor bike was purchased in order to obtain all necessary components for the engine, rather than sourcing all the components separately. In addition to the engine and transmission, the major components that were utilized from the original bike include the engine wiring harness, the engine control unit (ECU), and all fluid reservoirs. The manufacturer specifications provided for the Aprilia RXV 550 engine are listed below.

- **Engine Type**: 77 deg SOHC V-Twin 4-Stroke
- **Engine Displacement**: 549cc
- **Bore x Stroke**: 80mm x 55mm
- **Compression Ratio**: 12:1
- **Cooling**: Liquid
- **Fuel System**: EFI w/ two independent 40mm throttle bodies
- **Ignition**: Electronic
- **Starting System**: Electric
- **Transmission**: 5 – speed Manual
- **Final Drive**: Chain drive
2.2 Design Goals and Development Process

2.2.1 Lotus Engine Simulation

The team decided it was not practical to execute excessive dynamometer runs using the Dynomite dynamometer available to us in order to determine the engine’s power output either unrestricted or during intake and exhaust geometry testing. A head gasket failure occurred due to excessive engine heat generated by of lack of airflow over the engine when mounted to the dynamometer. It was later mentioned by numerous Aprilia technicians and RXV specialists that using a “water brake” type dynamometer is not a suitable method of dynamometer testing Aprilia engines due to the excessive long term loading required to produce a run.

Following the head gasket failure, the team spoke with Allen Noland, owner of Trans World Cycle located in Oakland, Maryland. Mr. Noland informed the team of a common problem Aprilia engines have with coolant leaking into the engine oil due to faulty silicone used to seal the two engine case halves together. Upon further discussion, Mr. Noland agreed to perform the laborious research task for us, as well as replace both head gaskets at a discounted rate. Due to these circumstances, the team made a decision to primarily use the Lotus Engine Simulation software in order to approximate the power output of the engine.

Lotus Engine Simulation can be used to simulate engine performance and gas dynamics for multiple engine configurations. By using the Lotus Engine Simulation software, and using all of the Aprilia RXV 550 specifications as inputs to the various intake and exhaust components of the engine, it was possible to obtain an approximate graphical representation of the engines unrestricted horsepower and torque, which can be seen below.
When compared to a dynamometer run of a stock Aprilia RXV 550 graphed below, it can be seen that the results obtained from the simulation software are very similar to actual results from dynamometer testing.

Because of the similarities of the simulation and actual data, it was determined by the team that the Lotus software would be a suitable tool for estimating the engine’s power output. Therefore, the simulation software was used to test various intake geometries, such as runner diameter and length,
plenum volume, as well as exhaust geometries, including primary length and diameter, secondary length and diameter. Based on the results from the software, the optimum theoretical intake and exhaust geometries were selected, fabricated, and mounted to the engine. The engine parameters, including AFR and ignition timing, were then tuned using the XV Tuner software described above, in order to account for the loss in airflow over stock due to the 20mm restrictor. Following the bench tuning, the car was taken out and tested under normal driving conditions, and tuning parameters were again changed based on driving performance.

2.2.2 Intake

The updated design for the 2011-12 season includes a dramatically different intake manifold than the one fitted from the factory, due to the Formula SAE’s restrictor plate rule. An easily accessible 20mm restrictor plate must be included in the intake, downstream of the throttle body. The factory intake utilized a velocity chamber and two separate throttle bodies consisting of short velocity stacks.

An AT Power 28mm throttle body, shown below, was selected after researching other teams’ prior experiences, as well as reading several technical documents regarding restrictor plate and throttle body design. It was found that only minimal gains could be generated from restrictor and throttle body redesign or modification of this unit.

![Photo 3: AT Power 28mm throttle body](image)

The AT Power unit includes the required 20mm restrictor as well as a tapered bore to minimize flow losses. Since the purchased unit is already optimized for the application, the primary focus of design is related to intake manifold design and the associated critical geometry considerations. The intake runner lengths and runner diameters for each cylinder, as well as the intake plenum volumes are the best areas for development, in order to make gains when operating with a restricted intake.

Due to time constraints the team also chose to purchase the accompanying air filter available from AT Power, shown below. With the same interest in conservation of time, the stock throttle position sensor (TPS) from the Aprilia engine was fitted to the 28mm throttle body and restrictor unit. Reusing the stock sensor eliminated the purchase cost and the time necessary to wire and calibrate a new throttle position sensor.
The intake is the major design component. As a first year team, there was little to no prior experience regarding knowledge of intake design for the Aprilia engine due to the rarity of the engine at competition. Last fall, a mock intake was created to best represent what the team envisioned an efficient geometry might look like. This intake lacked a large plenum volume and incorporated very large diameter intake runners. The large runner diameters did not create a high enough air velocity for proper fuel mixing. The engine did not run properly with the prototype intake.

Another major flaw of the prototype intake system was the orientation of the fuel injectors. When installed in the factory Aprilia throttle bodies, the fuel injectors pointed and sprayed in opposite directions, directly into the intake ports while the intake above had been designed with both fuel injectors pointing in the same direction. This meant that while the front injector was in the proper orientation, the rear injector was actually pointed and spraying away from the injection port of the cylinder head.

The first step of designing the current intake was to model the stock engine configuration using the Lotus Engine simulator. With basic parameters known, such as valve dimensions, and cam duration, the team modeled engine output. The results were compared to that of a stock Aprilia air intake system. Once the comparison was made, it was determined that the Lotus simulator did in fact accurately model results. Six intake geometries were modeled as starting points, and the graphical power results of each were compared. The intake that was the most efficient, and provided the greatest overall horsepower and torque (area under the horsepower and torque curves) was chosen and fabricated per the input geometries that were used as inputs to the Lotus program. A comparison of the stock vs. restricted power output of the Aprilia engine has been generated by the Lotus software.
This year, the team decided to re-use the AT Power pre-engineered throttle body and restrictor unit mentioned above, but now coupled to a much larger, one liter plenum which feeds two smaller 30 millimeter diameter by 30 centimeter long intake runners. One of the greatest improvements from the previous intake is the new intake plenum. While last year’s intake had sharp edges where the runner protruded inside the plenum, the current intake features two fiberglass molded bell mouths shown below, coupled to the runners inside the plenum in order to improve flow characteristics and create a better transition from the plenum to the runner.
2.2.3 Exhaust

The exhaust system employed on this year’s car is designed with both efficiency and sound level in mind. Efforts were focused mostly on control of sound level rather than on maximum performance. This decision was made to reduce the risk of system failures as well as reduce the risk of disqualification based on noise limit breaches. The exhaust system design utilizes header primary tubes in diameters similar to the stock Aprilia tubing; however, the new design will incorporate equal length headers that the stock Aprilia design could not accommodate, due to the engine configuration and position in the dirt bike chassis. An FMF Titanium PowerCore muffler with removable packing was selected, which allows the tuning of the exhaust noise level to meet the 110db limit under all driving conditions.

The exhaust system components are composed of 16 gauge 304 grade stainless steel, as the material properties provide acceptable temperature tolerance for the relatively high exhaust gas temperatures produced by the engine. The thicker stainless steel is also more practical for welding when compared to thinner gauge material, and stainless steel provides a more aesthetically pleasing finished product with exceptional resistance to corrosion over time.
When designing the exhaust system, the goal was to maximize power while staying under the 110dB limit set by the competition rules. The prototype exhaust assembled for early testing met the noise requirements but consisted of unequal primary exhaust runners, which is not ideal for maximizing power. The exhaust system was designed using the Lotus Engine Simulator. Primary runner and exhaust tube diameters, and primary runner length, were calculated before beginning the simulator, using equations from A. Graham Bell’s text as starting points.

**2.2.4 Engine Mounting**

The placement of the engine was determined in conjunction with the suspension team, in order to position the engine in such a way that will optimize their desired suspension design characteristics. 3D models of the chassis were analyzed, and a decision was made based on where the engine could be most effectively placed, with respect to accessibility, weight distribution, and the regulations set forth by SAE.

Because the Aprilia engine is relatively small and compact, it was easy to meet the above criteria and position the engine in a way that allows room for all required fluid reservoirs, as well as the intake and exhaust components, all while keeping the center of gravity as low as possible. Additionally, the new position also kept the engine itself and all attached components and reservoirs in similar relative orientation as they were when in the dirt bike chassis.

Once the ideal position for the engine was chosen, a clearance of 1 inch fore and aft was added to all mounting components to permit movement of the engine, which allows for loosening or tightening of the drive chain. The final position of the engine also provided adequate room for the positioning of the Torsen differential and the surrounding case assembly.
2.2.5 Engine to Chassis Integration

The factory Aprilia RXV 550 engine wiring harness has been modified for use in the FSAE car. Since the RXV (off-road) model was purchased, few modifications were required in order to adapt the harness for our uses, aside from lengthening sections of wire to accommodate for a different layout than the donor bike’s chassis. Modifications that were performed include the addition of a brake over-travel kill switch, a master kill switch, and removal of horn and headlight wires.

Figure 1: Stock Aprilia RXV 550 wiring diagram

2.2.6 Fuel Tank

In accordance with FSAE rules, all vehicles must have a fuel tank that meets various guidelines. The rules primarily govern the location and mounting restrictions for the tank, but also include stringent geometrical guidelines that also need to be followed. The easiest mounting position, and the one chosen by the team, states that the tank must be located within the boundaries of the side impact structure, while having the filler neck positioned in a way to prevent leakage in the event of a rollover. The tank must also incorporate a vent, drain, and a sight tube mounted to the filler neck to display the maximum

Photo 8: Engine located in chassis, set in the rearmost possible position.
fuel level for the tank. Beyond these restrictions, the fuel tank design is primarily focused upon minimizing weight and size while still being able to hold enough fuel to complete the endurance event.

Aluminum was selected as the material for constructing the fuel tank because of its light weight and its relatively low price and ease of fabrication. A sheet thickness of 1/16 was chosen to provide sufficient strength and durability. Interior baffles were used in order to minimize fuel movement while the car is being driven.

![Figure 2: Aluminum fuel tank, approximate volume of 2.1 liters](image)

![Figure 3: Inner fuel tank baffles prevent fuel from splashing while the car is being driven](image)

The location and packaging of the fuel tank were primary considerations in its final design. Since the factory in-tank fuel pump on the RXV 550 could not be used, a Walbro GSL 414 in-line fuel pump was selected to ensure adequate fuel delivery, while allowing the fuel tank to remain compact. The Walbro pump is two inches in diameter, and 6 inches in length. This allows for tighter packaging of the fuel tank, since the tank does not have to be provisioned for a large in-tank unit.
2.2.7 Data Acquisition

In order to properly tune all aspects of the car while improving driver performance, a data acquisition system is an important and necessary aspect of the car. With the goal of significantly reducing engineering time by improving the team’s ability to diagnose possible problems, a pre-designed data acquisition system was purchased, along with a fully programmable dashboard style display unit. Both units are manufactured and sold by Race Technology. The DL-1 is a powerful system capable of logging data that includes 3-axis accelerometer, GPS, 4-wheel speed, and eight 12-bit analog inputs simultaneously to a compact flash card. It also features a powerful and easy to use data analysis software package, which allows for easy interpretation and manipulation of the recorded data. Measured parameters include accelerometer and GPS data, exhaust gas temperatures, and universal exhaust gas oxygen (UEGO) for both cylinders, as well as throttle position, engine RPM, water temperature, and gear selector position.

Photo 9: Race Technology Dash 2 and DL-1 data acquisition system

The Race Technology Dash 2 unit packaged with the DL-1 data acquisition system is capable of displaying more real time data to the driver than the standard Aprilia dash. This data is also logged by the data acquisition system. Since the Dash 2 unit came packaged with the DL-1 unit, little interfacing was required in order to display the logging parameters on the dash display, making it an ideal system for our application.
2.2.8 Tuning

The engine control system retains the factory Walbro ECU engine control by using Western Racing Developments XV Tuner tuning software. This software allows the user to tune fuel and spark delivery for each cylinder individually. Both cylinders of the Aprilia RXV 550 have exhaust gas temperature and lambda sensors, allowing the conditions of each cylinder to be closely analyzed during testing and competition.

The Western Racing Developments tuner was provided to the team by Kurt West of Calgary, Alberta Canada. Mr. West has developed the software package offered with his tuning cable, which allows for full programming, and uploading of different fuel maps to the Walbro engine control unit. Since the XV Tuner was developed specifically for the Aprilia RXV/SXV line of motorcycles, it is easy to use and can communicate directly and effectively with the factory engine control unit.

The XV Tuner software was used to adjust tuning parameters such as fuel delivery in order for the engine to run with the 20mm restrictor. When used in conjunction with the DL-1 data acquisition unit it is possible to adjust tuning parameters based on observed engine parameters and obtain a safely and smoothly operating engine. In addition to the parameters being logged by the DL-1 unit, it is convenient to be able to view other parameters such as throttle position (TPS), which is automatically sampled by the engine control unit (ECU) itself and can be displayed under the Realtime Data tab of the XV Tuner software.
2.2.9 Cooling

One of the obstacles in using a new, rather unfamiliar engine is the lack of data available in FSAE applications. During testing with the factory engine, every part of the factory cooling system was utilized. Engine coolant temperatures reached the higher end of the ideal temperature range, with temperatures in excess of 225°F. The slow moving, high loading autocross type driving in which the car was tested directly contributed to these high coolant temperatures. Since the two smaller, single row radiators led to high coolant temperatures and flow losses, a larger 3-row radiator was fitted, along with an electric cooling fan, controlled by the engine control unit (ECU). This setup was chosen in order to improve cooling and increase efficiency of the coolant system by reducing flow losses. The new more efficient setup replaced the stock cooling system seen below.
The mounts for the two small factory radiators were removed from the frame, shown in location above, and the new radiator was placed in the left side pod beside the driver’s cockpit.

2.2.10 Lubrication

The car incorporates the factory Aprilia dry sump type oiling system. This is a feature that many other teams must add to their engines, however, the Aprilia engine offers this as standard equipment from the factory on the RXV model. The stock system uses rubber oil lines that are clamped at each connection. An oil temperature sensor is incorporated to the lubrication system with real time temperatures displayed on the dash unit. Oil temperature is a crucial factor in engine operation. In order to have a properly running engine, the oil must be allowed to reach the desired temperature before any load can be applied to the engine. Figure 18 below shows the setup of the factory dry sump lubrication system.

2.2.11 Engine Conclusion
Overall, the Aprilia RXV 550 engine provides a great package for a Formula SAE car. The excellent power to weight ratio stands out when comparing to other naturally aspirated motorcycle engines. With the competition spec 20mm restrictor intake in place, our team was able to retain the stock power band with minimal losses when compared to the factory engine, which was quite an accomplishment in itself when dealing with the large airflow pulses of a two-cylinder engine. Based on the compact size of the new intake and exhaust designs, as well as of the Aprilia engine itself, the team was able to work alongside the suspension team during the chassis redesign process in order to package all of the newly designed components tightly and efficiently into the car’s frame.

References