STANADYNE Goliath Direct Injection Pump Program Performance Report

PROJECT TITLE

Assessment of 12 mm bore (Stanadyne Goliath)
Direct Injection High-Pressure Pump

RECEPIENT ORGANIZATION

Stanadyne Operating Company LLC.
405 White Street Jacksonville, NC 28546. USA
https://www.stanadyne.com/
DUNS: 11-906-2582

PRINCIPAL INVESTIGATOR

Mr. Srinu Gunturu
Chief Engineer
Stanadyne Operating Company LLC.
C: (860) 712-3474 O:(910) 353-3666
sgunturu@stanadyne.com

SUPPORTING INVESTIGATORS

Mr. Clark Klyza (Stanadyne Operating Company LLC)
Mr. Eric Suits (Katech Engineering LLC)
Mr. Chris Dorch (Dorch Engineering)
Mr. Ajay Rajeev (SPOOL Performance)

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Executive Summary

Functional Description:

Shown in “Figure 1” is an overall system schematic illustrating the fuel system for an internal combustion engine. The low-pressure supply pump pressurizes fuel from the fuel tank and delivers it to the high-pressure pump housing through an inlet fitting. The fuel then passes through a pressure damper that attenuates pressure fluctuations then through a normally open control valve. Fuel is drawn into the pumping chamber on the plunger downstroke and pressurized on the plunger upstroke. The upstroke and downstroke of the plunger are controlled through the engine camshaft. The control valve is acted upon by the control valve spring and solenoid to control the quantity of fuel delivered by the high-pressure pump. Desired delivered volume is accomplished by the accurate timing of the control valve closing relative to the plunger upward travel position. Pressurized fuel flows through the outlet check valve and high-pressure line then into the common rail that supplies the engine fuel injectors. Because the injectors are fed from a common rail, injector timing is flexible. Desired rail pressure is controlled by a closed loop feedback. The signal from the rail pressure sensor is compared to the desired rail pressure value in the Engine Control Unit (ECU) then actuation of the control valve is adjusted as required to obtain desired rail pressure. A pressure relief valve is required to protect the high-pressure system in case of a system malfunction. It is housed in a common discharge fitting assembly, which also houses the outlet check valve. A pressure relief valve is used for control of the maximum system pressure to a predefined limit, thus protecting the fuel system components.

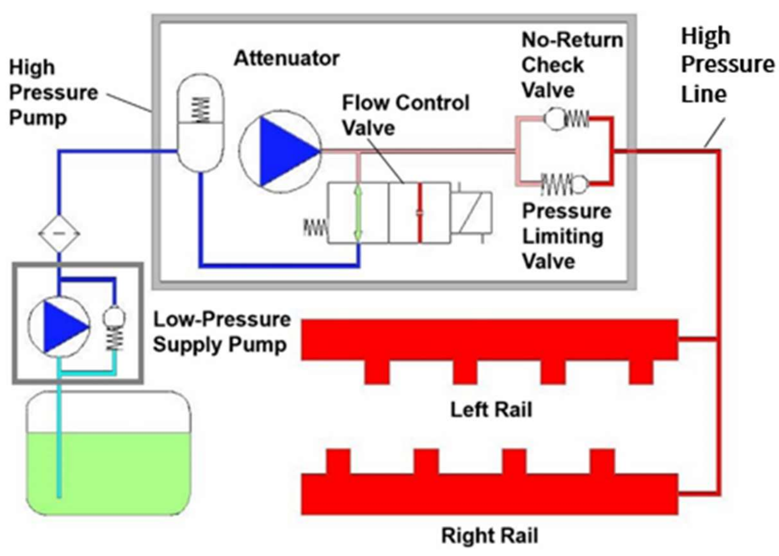


Figure 1: Fuel System Schematic

An example of a Gasoline Direct Injection (GDI) fuel system engine installation is shown in “Figure 2”. In this example we can envision the path of the fuel flowing into the inlet line to the pump inlet, through the damper assembly, through the pump according to control valve actuation, past the check valve, into the fuel lines, and to the rails where the stored high-pressure fuel is available to supply the fuel injectors.

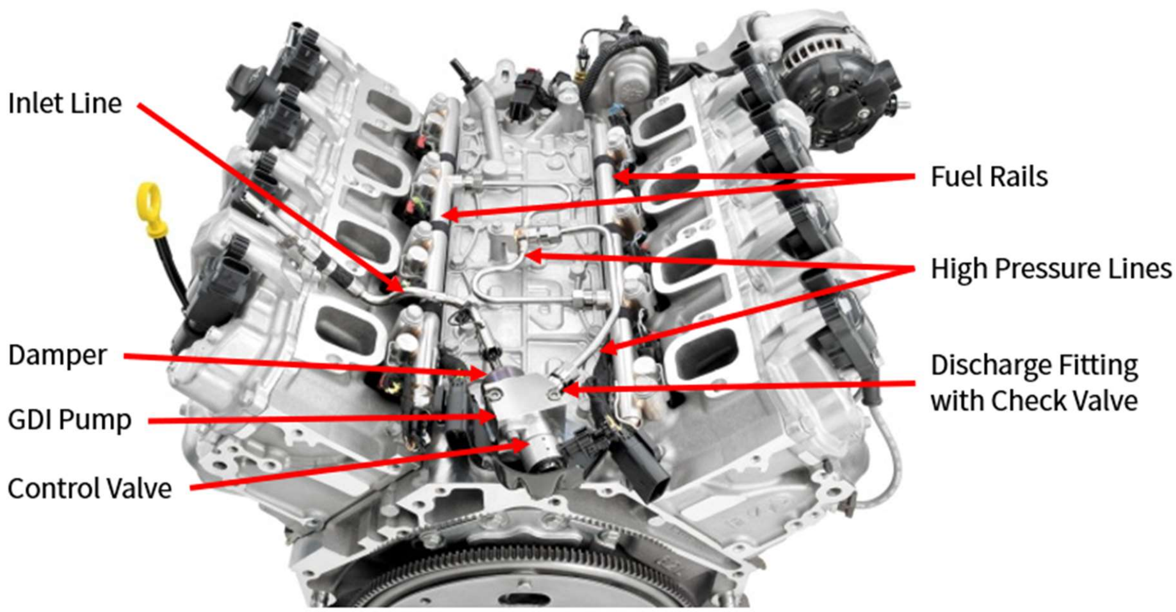


Figure 2: GDI Fuel System Installed on Engine

High Performance and Aftermarket Pumps:

Stanadyne has been producing high performance GDI pumps for automotive applications since 2013 with the introduction of the SP1250, commonly referred to as an “LT1”. This pump has a plunger diameter of 10.5 mm with a standard plunger stroke of 5.7 mm and pressure capability of 100 bar. The SP1250 has an advertised volumetric delivery of 1,250 mm^3/rev utilizing a three-lobe camshaft providing a 5.7 mm plunger stroke at 2,400 prpm (pump rpm), at maximum delivery. This pump is used across a wide range of applications.

In 2014, due to increased demand for higher volume delivery and increased pressure, Stanadyne introduced the SP1550, which is commonly referred to as an “LT4”. The SP1550 has a plunger diameter of 11.5 mm. The volumetric delivery is 1,550 mm^3/rev at 200 bar utilizing a three-lobe camshaft providing a 6.0 mm stroke at 2,400 prpm at maximum delivery. This pump is utilized in high-performance automotive and light-duty truck applications. This SP1550 maintains bragging rights as the largest displacement of any pump utilized in OEM automotive applications.

The SP1250 and SP1550 pumps are shown side by side in “Figure 3”. As seen, the two pumps are similar in shape with the SP1250 having a shorter housing and smaller diameter damper housing.

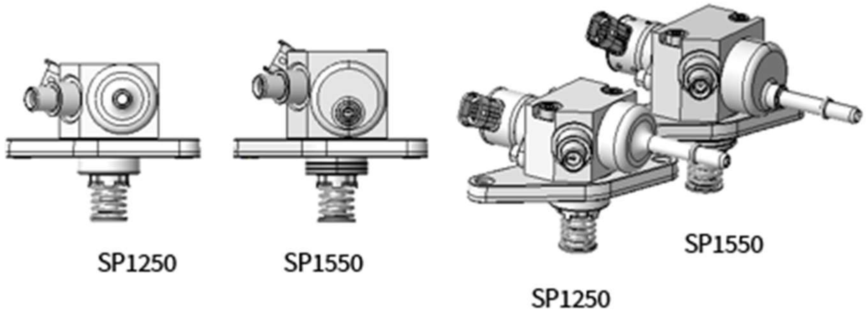


Figure 3: SP1250 and SP1550 Comparison

These performance pumps, particularly the SP1550, are widely utilized in the aftermarket performance market. In 2023, Stanadyne engaged the customers to determine what configurations the end user would like to have available for various applications. Stanadyne designed, built, and delivered SP1250 and SP1550 pumps to the aftermarket. These custom pumps have a variety of options on the inlet and solenoid mounting, allowing for custom applications on a variety of engine platforms. A sample of the various configurations is shown in “Figure 5”. Pressure capability on the SP1250 was increased to 250 bar and on the SP1550 was increased to 350 bar.

The custom configurations and higher-pressure capabilities of SP1250 and SP1550 were well received and led to further development based on customer requirements. The desire for higher flow and pressure led Stanadyne to develop a larger volume 350 bar capable pump in 2023 to satisfy the fuel delivery demands of high-horsepower applications. The new pump is externally analogous to the SP1550 design, but fitted with a 12 mm plunger, has internal modifications, and can accept up to 8 mm of plunger stroke. The new pump is designated the SP2100 and has the “Goliath” designation. The Goliath can deliver up to 2,100 mm3/rev at 350 bars using a three-lobe camshaft with up to 8.0 mm plunger stroke. An example of Goliath is shown in “Figure 4”.

Figure 4: SP2100 Goliath

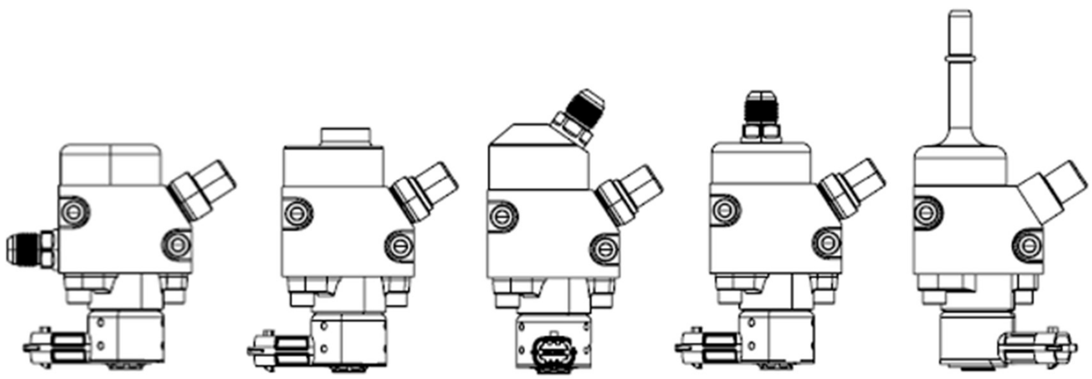


Figure 5: Examples of Aftermarket Performance Pump Variants

A delivery versus speed plot at 200 and 250 bar is shown in "Figure 6" and "Figure 7". As shown in "Figure 6," the SP1250, SP1550, and SP2100 all perform extremely well at 200 and 250 bar throughout the speed range, with minimal drop in delivered volume at higher pressure. The differences in delivered volume between the three pumps at 200 bar rail pressure is illustrated in "Figure 7". Delivered volume from the SP1550 is shown in "Figure 7" to be approximately 24 percent higher than that of the SP1250. Delivered volume of Goliath is shown to be approximately 22 percent greater than the SP1550 and approximately 50 percent greater than the SP1250.

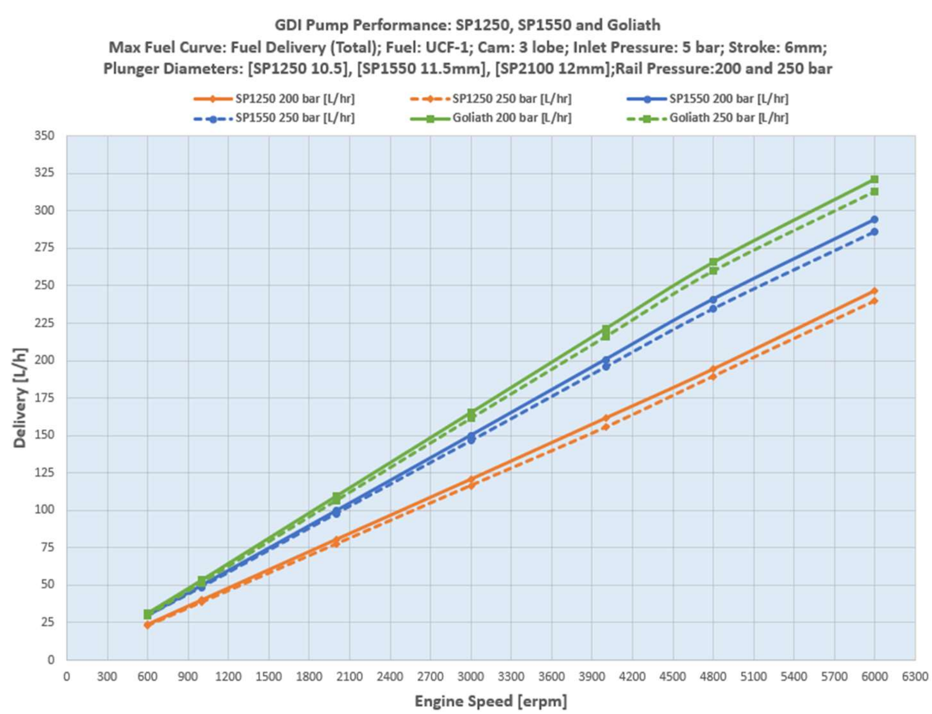


Figure 6: SP1250, SP1550 and Goliath: Delivery at 200 and 250 bar

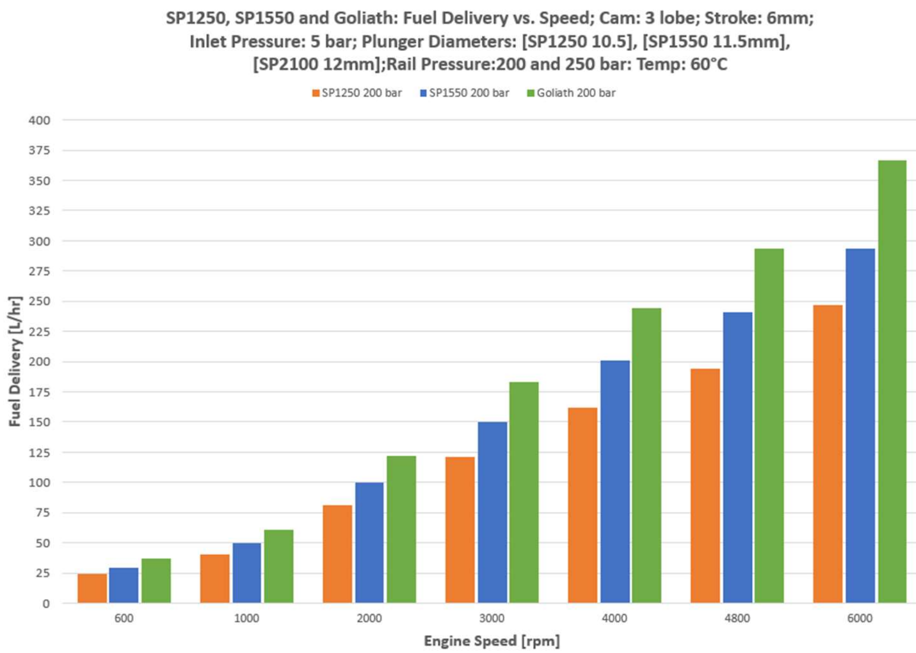


Figure 7: SP1250, SP1550 and Goliath: Delivery at 200 bar

The SP1550 and SP2100 delivery versus speed plots at 250 and 350 bar with a 6 mm stroke are shown in "Figure 9" and "Figure 10". As shown in "Figure 9," the SP1550 and SP2100 both perform exemplary at 250 and 350 bar throughout the speed range, with minimal drop in delivered volume at higher pressure. The differences in delivered volume between the two pumps at 350 bar rail pressure is illustrated in "Figure 10." Delivered volume from the Goliath in "Figure 10" is shown to be approximately 12 percent greater than that of the SP1550 at 350 bar.

Goliath Extreme Performance Aftermarket Pumps:

The Goliath pump has been shown to provide significantly higher fuel delivery than the SP1550 throughout the speed range at up to 350 bar rail pressure. However, much higher deliveries are desired for extreme power applications, leading to the development of higher lift capability on Goliath's 12 mm plunger. The Goliath pump can run with up to an 8 mm stroke. An example of a Goliath pump mounted on engine is shown in "Figure 8".

Figure 8: SP2100 Goliath on Engine

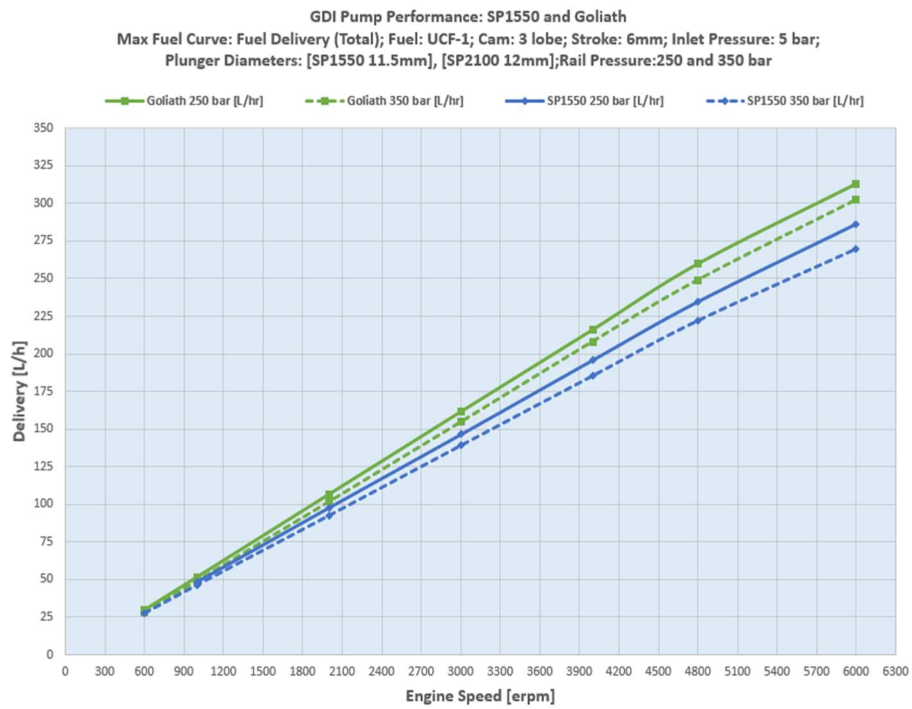


Figure 9: SP1550 and Goliath: Delivery at 250 and 350 bar

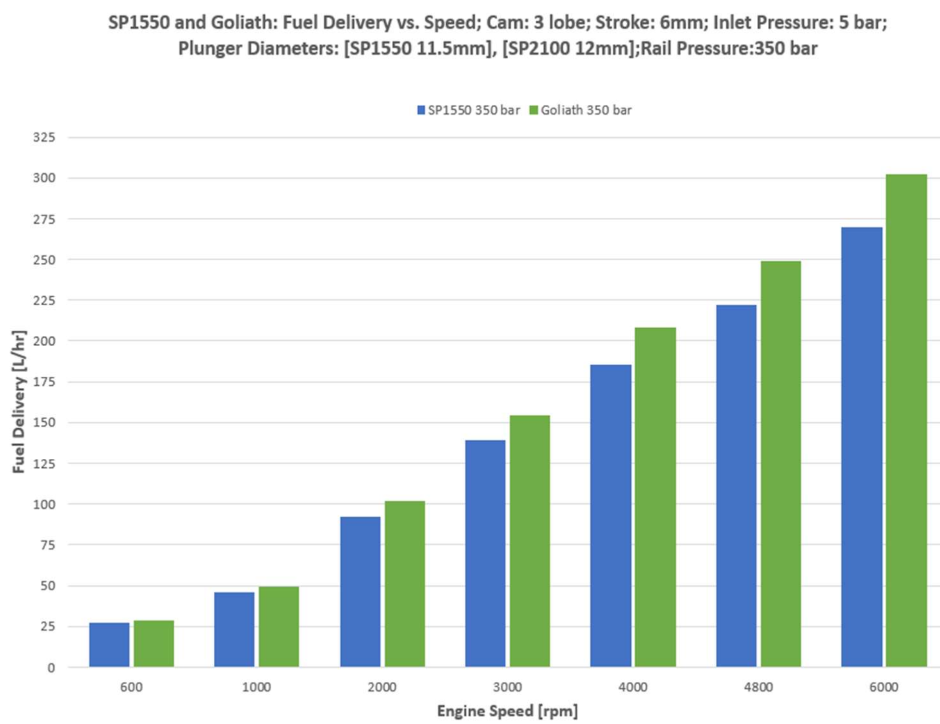


Figure 10: SP1550 and Goliath: Delivery at 350 bar

The delivery gains associated with increased stroke on the Goliath are shown in "Figure 11." An increase of approximately 29 percent in delivered volume can be realized going from 6 mm to 8 mm of plunger stroke. Moving to such high plunger strokes is not without issues, making such a change quite challenging.

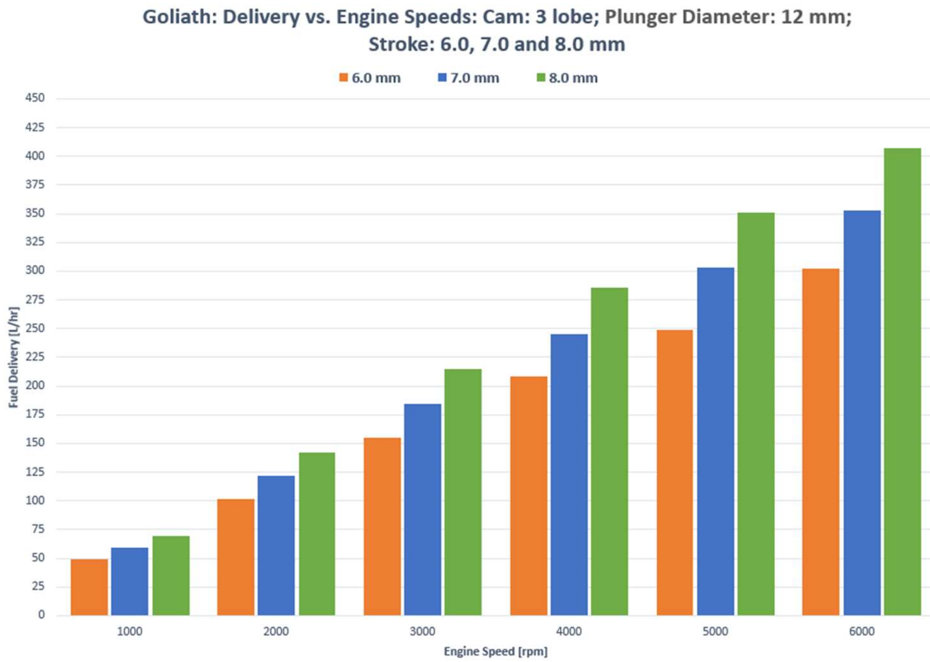
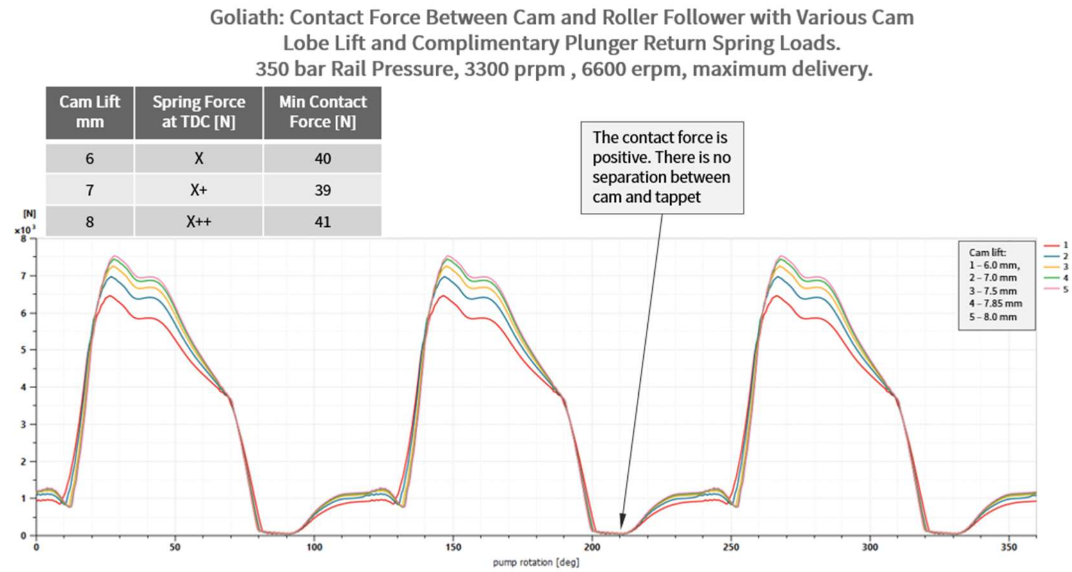


Figure 11: Goliath: Delivery with Varying Plunger Stroke

Goliath: Challenges Associated with High Stroke:

In a GDI pump application, the plunger reciprocates in a sleeve. Cam displacement determines the plunger stroke and displaced volume. On the pumping or upward stroke, the cam forces the plunger upwards compressing the plunger return spring. Stored energy in the plunger return spring is utilized to maintain cam contact on the downward filling stroke. With the development of larger diameter plungers and higher displacements, designing a plunger spring with adequate force to maintain cam/roller contact on the downward stroke is problematic given the existing space constraints.

The Goliath's large plunger combined with an increased stroke results in higher mass, plunger velocities, and accelerations. The increased inertial loads associated with increased lifts needed higher load spring, having appropriate force installed prior to implementation of an increased stroke pump. Shown in "Figure 12" is an example of the analysis required to assure proper pump operation with higher strokes. We can see that increased stroke results in higher loads being generated between the cam and the roller follower. Maintaining sufficient contact force throughout the cycle requires complimentary plunger return springs to maintain minimum contact force.



Cam Lift mm	Spring Force at TDC [N]	Min Contact Force [N]
6	X	40
7	X+	39
8	X++	41

Figure 12: Goliath: Cam Contact Force, Various Lifts, and Return Spring Force

To achieve the spring force required for the Goliath high-lift plunger in the allowable package size, a nested spring design was selected. The nested spring design is a spring within a spring, allowing a very high force spring to be installed in the available area. Larger upper and lower spring retainers were designed to accommodate the new spring configuration. The nested spring configuration for the Goliath is shown in “Figure 13.

Many analyses were required for the Goliath pump, in addition to the contact forces. Internal flows and pressures are modeled and optimized to assure pumping chamber pressure is acceptable and losses are minimized. Finite element analysis is required to assure the pump is structurally sound. All these various analyses are iterated to optimize the pump and provide a high safety factor and high confidence in the design.

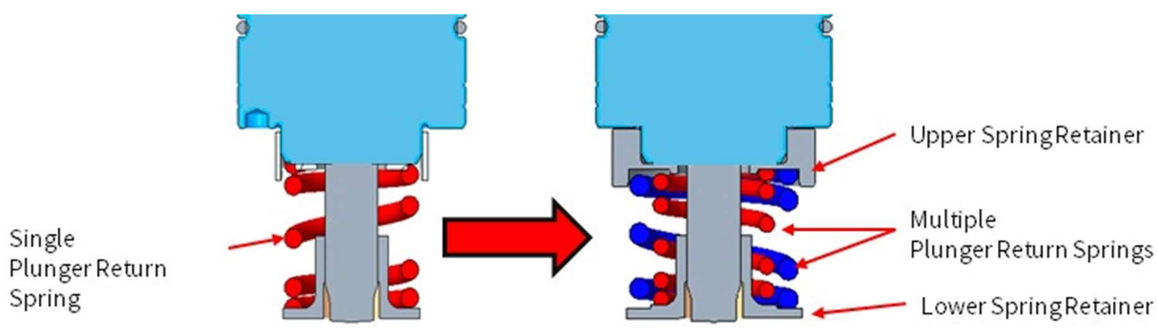


Figure 13: Goliath: Nested Plunger Return Springs

Goliath: Proof of Concept, What Really Matters:

We have looked at various aspects of the Goliath pump delivery, pressure, analysis, various configurations, etc. This leaves one with confidence that this high-performance pump can really raise the bar on engine performance. After all the analysis and testing, it is time to see what really matters: how does the Goliath perform on engine in the dyno. We are fortunate that our customers are willing to share dynamometer data on select engines fitted with Goliath pumps supplying the fuel required to achieve massive horsepower gains.

Shown in “Figure 14” are plots of horsepower and torque from Dorch Engineering on a stock BMW 340i fitted with the Goliath pump. The stock engine achieved 311.8 horsepower and 315.7 ft-lbs. of torque. The modified engine using the Goliath achieved 823.7 hp and 765.6 ft-lbs. of torque. The Goliath pump enabled this engine to see a 264 percent increase in horsepower and 242 percent increase in torque over the stock baseline.

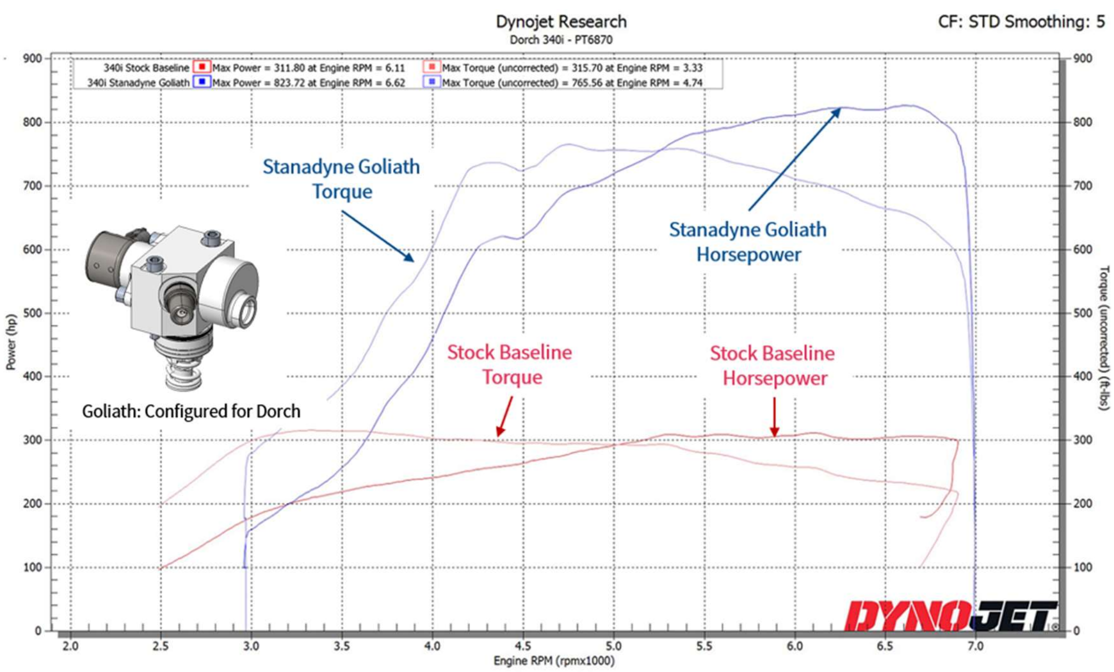


Figure 14: Goliath Fitted on a BMW340i at Dorch Engineering

Spool Performance incorporated a custom configured Goliath pump in their twin-turbo Mercedes M177 LS2 engine, achieving 1040 WHP with 1000 ft-lbs. of torque on E85 fuel. The performance chart from Spool is shown in “Figure 15.” According to Spool, there is adequate fuel delivery margin from the Goliath for additional performance gains.

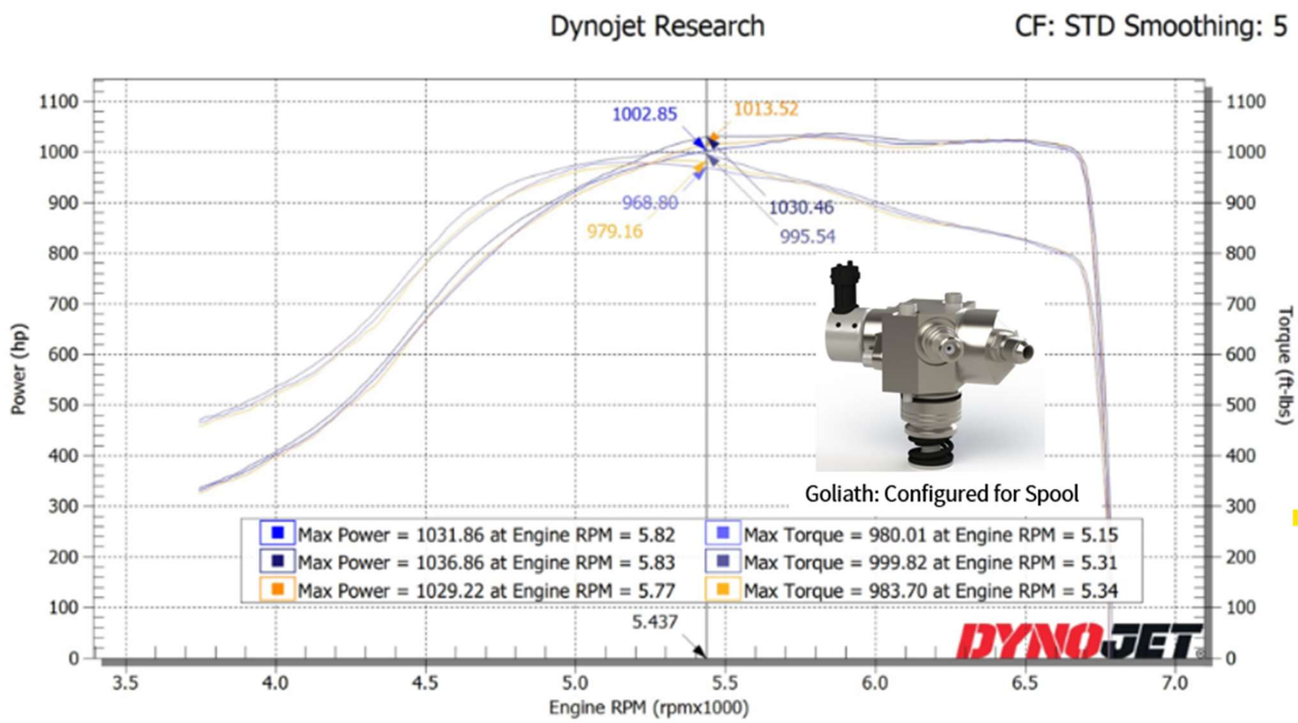


Figure 15: Spool Performance Built Mercedes M177 LS2 Engine

Another example of what can be achieved using the Goliath is illustrated in “Figure 16.” Katech Performance fitted a Goliath on a 388 cu LT V engine with a 7.82 mm cam lift and ran it on race gas to achieve an impressive 1,475.3 (SAE J1349) horsepower with 1,173 ft-lbs. of torque (SAE J1349). “Figure 17” shows the same engine using E85 achieving 1,254.9 horsepower with 996 ft lbs. of torque. A picture of the engine on the dynamometer is shown in “Figure 18.”

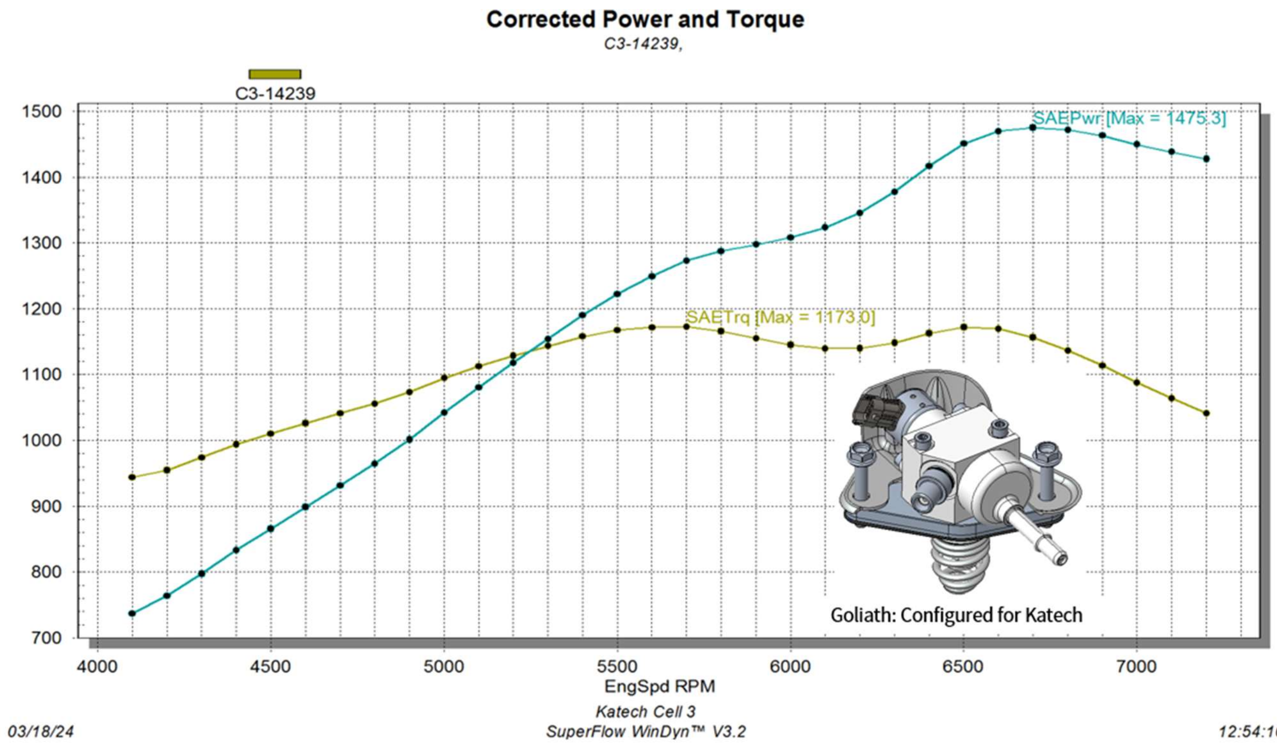


Figure 16: LT V Engine Fitted with Goliath using Race Gas at Katech Performance

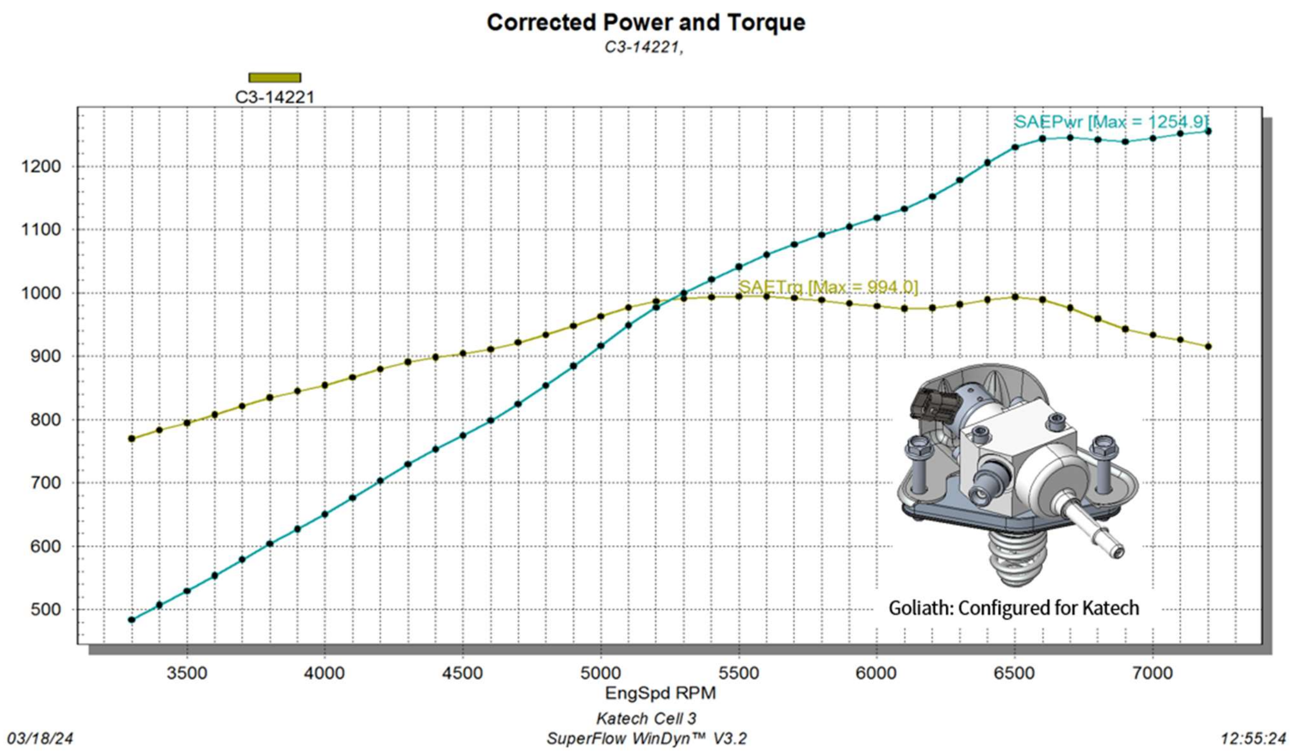


Figure 17: LT V Engine with Goliath using E-85 at Katech Performance

Figure 18: What it's All About - Goliath and Unconstrained Power

Stanadyne aftermarket performance and Goliath pumps have enabled tremendous performance and dependability gains for tuners and automotive enthusiasts. Stanadyne highly engineered aftermarket pumps provide the highest performance, unparalleled quality, and excellent value to the high-performance fuel system aftermarket.

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