A Whitepaper for

Formula 1 High Speed Engine Test Stand

Point of Contact:
Scott Tedesco
6220 Culebra Road
San Antonio, Texas 78238
(210) 522-3209
scott.tedesco@swri.org

Formula 1 Engines

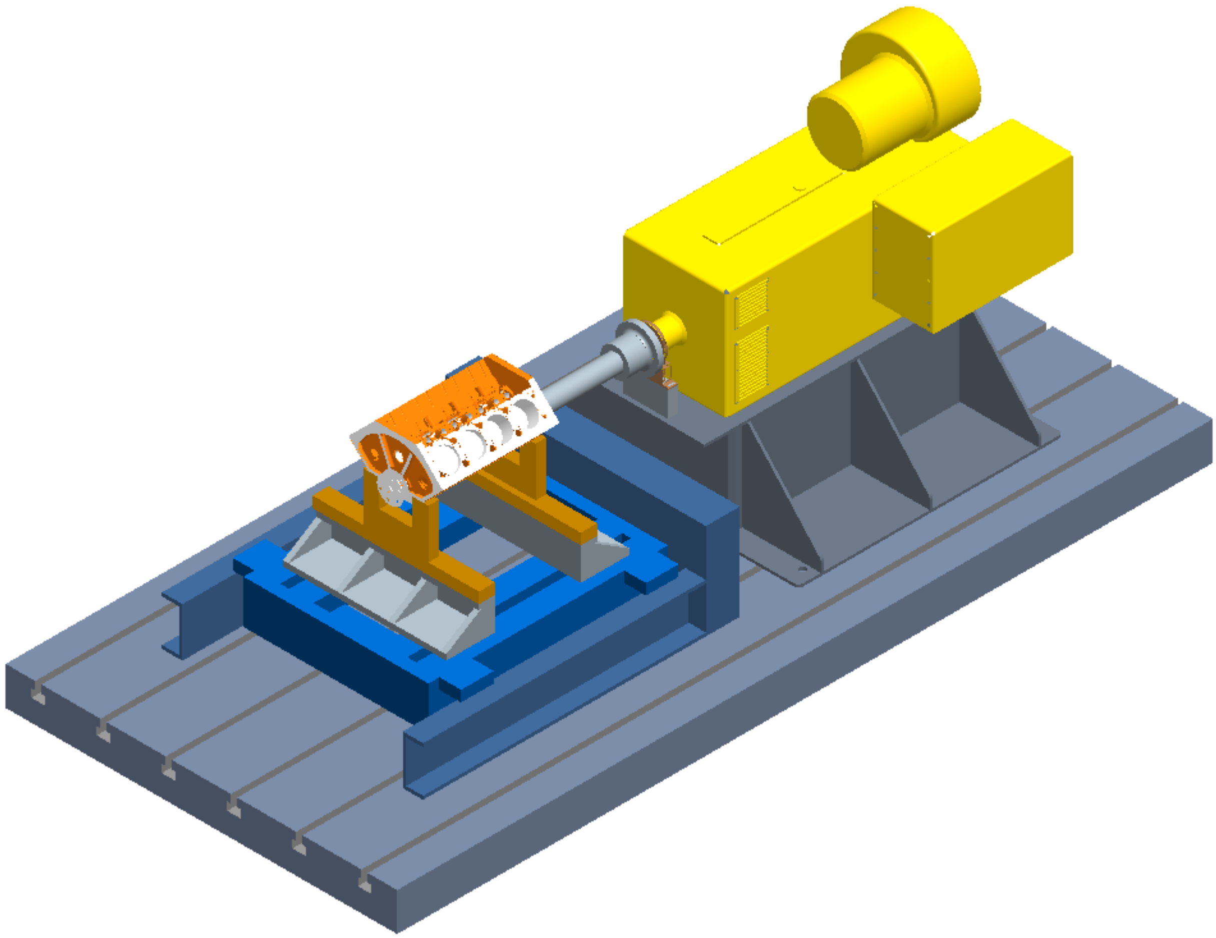
The nature of Formula 1 is such that it requires high horsepower engines operating at very high speed conditions. Operating conditions in a race environment stress these engines extensively, pushing them to their design limits. Due to operation at extreme conditions as well as the constant design changes inherent in the highly competitive sport, Formula 1 engines must be rigorously tested to ensure the engine design meets all operational requirements. With engine speeds of 15,000-18,000rpm, high ramp rates, and engine power over 800bhp, a high performance test stand with specialized features is required to properly evaluate these engines to assure maximum performance on race day.

Test Stand Capabilities

SwRI can provide a test stand that is designed and fabricated to simulate the loading conditions experienced by a Formula 1 engine on a particular race track. The primary function of this test stand would be to provide variable loading over the entire speed and power range of the engine, with maximum performance capabilities of:

- Maximum speed: 21,000rpm
- Maximum torque: 215 lb-ft @ 17,000rpm
- Maximum horsepower: 850bhp @ 19,000rpm

The key components of this test stand would be an ultra low inertia dynamometer, regenerative variable frequency drive (VFD), high speed coupling, instrumentation, high-speed data acquisition, and a real time controller providing hardware-in-the-loop (HIL) simulation. The figure below shows a conceptual design for the test stand.



The dynamometer will be an 850hp, four pole permanent magnet dynamometer with a top speed of 21,000rpm and a maximum torque condition of 215 lb-ft at 17,000rpm. Due to the nature of the four pole design, the diameter of the dynamometer is reduced, effectively minimizing the dynamometer's inertia. The dynamometer shaft and Class H winding insulation are designed such that the dynamometer can withstand a continuous 200 percent over-torque condition. The critical speed of the shaft is 20 percent above the maximum speed condition. Low inertia characteristics of the dynamometer allows for accelerations up to 100,000rpm/sec. The shaft is supported by magnetic bearings which effectively eliminates any vibration since it is balanced about the center of mass rather than the center of geometry. Dynamometer cooling will be provided by both a water jacket around the stator and air blown cooling between the rotor and stator. The air blown cooling system fan will be independent of the dynamometer shaft to provide constant cooling throughout variable speed states. A health monitoring system of the dynamometer will consist of position monitoring for magnetic bearings and temperature monitoring of the stator and cooling jacket.

A 1000Hz regenerative variable frequency drive (VFD) rated for 480VAC will control the dynamometer in current, voltage, or speed modes. This VFD is actively rectified with insulated-gate bipolar resistors (IGBT) whose backplane is water cooled. Optical isolation is used to obtain maximum signal quality. The carrier frequency is rated at 10 times the fundamental frequency (600Hz), providing rectification up to 6000Hz. The VFD can handle 200 percent current overload conditions for up to 5 seconds to support the high accelerations of the dynamometer. Signal quality over the entire operational range is very high, with maximum distortions less than 4 percent. The VFD communicates via Modbus RS-232 protocol at 38,400 baud. The VFD has voltage, current, frequency, and temperature protection and has a fusible disconnect.

A real time controller would run variable loading, variable speed testing. The controller will provide hardware-in-the-loop (HIL) simulation, creating a test environment in which the engine will think and act as if it is in a racecar. Physics based models of dynamic systems such as the transaxle, half shafts, and brakes will be incorporated into the HIL simulation, providing real-time variable loading feedback to the dynamometer. The controller would provide capabilities for both automatic and manual operation. A block diagram of the system is shown on the following page.

The high-speed data acquisition system would provide signal conditioning and high-speed, high-resolution data collection and recording. Instrumentation would include an inline torque sensor, speed sensors, pressure transducers, and thermocouples.

A high speed coupling will connect the dynamometer to the engine. This coupling will provide for vibration mitigation and shaft misalignment correction throughout the entire speed range.

The support would provide easily accessible, vibration and shock mitigating engine mounts for efficiently switching test articles and minimizing stand vibration, and it would have a flexible configuration capable of accepting different dynamometers.

Over the past 60 years, SwRI has operated 240 dynamometers recording 22 million hours of engine testing. SwRI has been at the forefront of HIL systems for engines and transmissions.

FORMULA 1 ENGINE TEST STAND
HARDWARE-IN-THE-LOOP SYSTEM DIAGRAM