A Whitepaper for
Engine Pitch and Roll Oil Aeration Simulator

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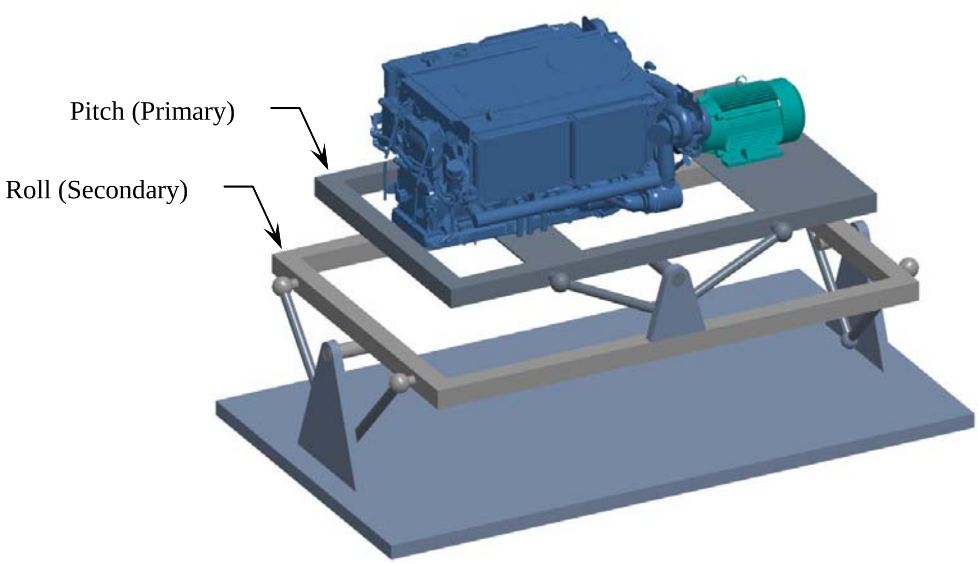
Aerated Fluid/Oil Churning

Speed dependent losses or parasitic losses in reciprocating engines have long been an area that engineers have strove to understand so as to reduce their magnitude. Parasitic losses are typically linear relative to engine speed. During normal, level smooth road operation oil churning and oil aeration losses typically amount to 2-3% of the total power production. These losses can increase significantly during operation over undulating terrain which causes the engine oil to pitch and roll. Furthermore, the **rate of change** at which pitch and roll conditions are input to the engine oil can increase these losses to 5-6% of an engine's total power output. Losses at these levels justify a serious investigation to quantify their magnitude and characteristics, so that oil system improvements can be made.

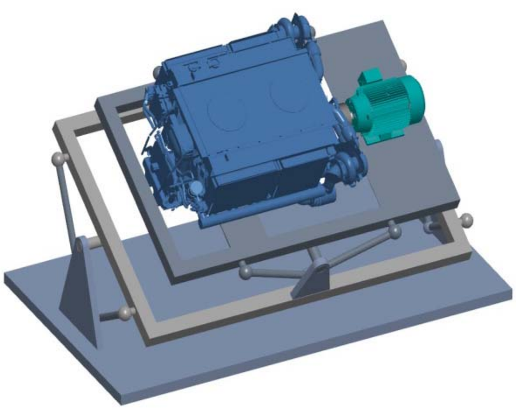
Investigation

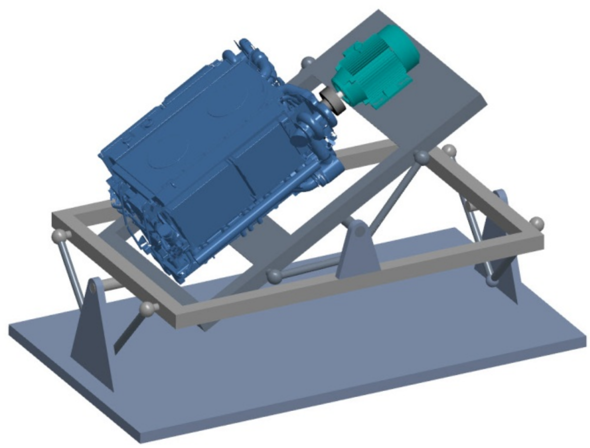
To enable the investigations, it is proposed that a programmable, dynamic pitch and roll simulator that utilizes a non-firing engine be designed and built. The primary function of the test stand would be to measure crankshaft rotational speed, torque and fluid aeration. Via the flywheel, the crankshaft of the engine would be connected to and rotated by an electric motor capable of speeds from 0+ to 4000+ rpm. This property of the simulator is shown in the figure below.

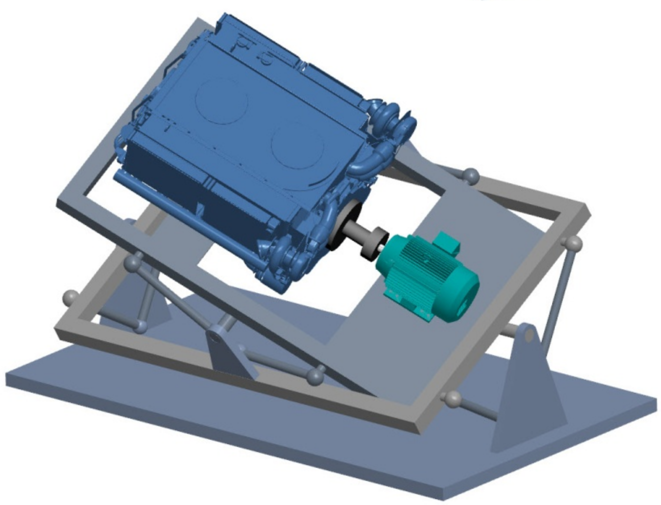


In addition, heating coils surrounding the engine would be installed to provide for realistic oil operating temperatures up to 300+°F during testing. Studies to date have indicated that the magnitude of aeration, churning and sloshing losses are very engine specific, and that the losses increase dramatically as temperature is increased. With increases in temperature, the surface tension of the oil decreases such that more air can be entrained into the engine oil. To the engine's detriment, increased amounts of entrained air in the oil reduces the oil's ability to cool and lubricate moving parts in the engine, which leads to power and efficiency losses through elevated temperatures and friction. Power losses and wear can be significant in areas such as the piston ring to liner interface because of these frictional increases.

This design of the simulator would create oil windage from the crankshaft movement and bulk oil motion through test stand movements within the pan and resulting in oil aeration. In order to simulate pitch and roll conditions that greatly increase the bulk oil motion (sloshing affect), and in turn increase oil aeration, a dual gimbal system would be necessary. This system would consist of an engine mounting spindle frame that would provide realistic, enhanced **pitch** affects. This primary mounting frame would in turn be mounted in a secondary frame that would provide realistic, enhanced **roll** affects. This two degree of freedom frame structure is shown below in various pitch and roll positions.







Programmable hydraulic actuators along with the required controls will be installed in order to provide various dynamic pitch and roll rotation speeds. Finally, any combination of the two can be programmed.

Technical Summary

It is easy to visualize how this test fixture can be utilized to investigate and characterize oil aeration and reduce its detrimental effects on modern heavy duty diesel engines. This simulator provides for realistic combinations of elevated oil temperatures, engine speeds, and pitch and roll rotation speeds.

To date the majority of aeration reduction studies have been done on **passenger** car applications with the engine oil pan in the **level** position. NASCAR owners have long recognized this problem and have specifically addressed this from a steady-state, roll perspective which occurs on banked ovals. There have been no engine oil churning, sloshing, aeration studies done on extreme combinations of pitch and roll, nor has the rate of change of pitch and roll been investigated. As a result, no studies have been conducted to address specific aeration hardware solutions which have the potential to be very cost effective.

Reductions in parasitic losses require an investment in the application of engineering labor **only**, as existing parts need only be redesigned. This is in contrast to reductions in load dependent losses that typically require stronger, heavier parts. In addition, parasitic losses, which are a first order effect, are resident within an engine whenever it is operating. This is in contrast to part time dependent load second and third order losses. Reductions in parasitic losses would allow additional engine power production within the same space package to be realized. It should also be noted that aerated fluid reduces engine life due to the reduction in elastrohydrodynamic lubrication within the engine bearings.

The realization of an additional 5% gain in power (and power density) in current and future engines based upon reductions in engine designs to reduce aeration affects is an immediate achievable goal.

Southwest Research Institute's Past Experience

SwRI has been actively involved in investigation engine oil aeration in passenger car engines for the past 25 years. It has built and operates a number of specialized test rigs that conduct standardized industry tests. The focus of these test rigs is associated with oil additives and formulations for SAE ratings seen on the back of engine oil containers.

SwRI has actively worked on numerous liquid sloshing problems in tanks such as in liquid propellant used in satellites, oil tankers and fire truck water/fire suppressant tanks. Studies have included investigations into frequency, planar motion and first and second order effects. Quantifying bulk oil motion and crankshaft windage effects will present opportunity for oil pan and oil pickup optimization that could potentially increase the range of operational angles without oil pump cavitation and subsequent engine oil aeration with the performance detriments listed previously.