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THE FINAL SERIES OF OILS TESTED AS A POTENTIAL SOLUTION TO THE GALVESTON FERRY OPERATIONS (GFO) ENGINE FAILURES

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TxDOT Project 0-5532: Galveston Ferry Operation (GFO) Engine TxLED Failure Assessment, Solution, and Implementation

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Performing Organization:	Sponsoring Organization:
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1. Introduction

Following the recommendations of Project 0-4576, the Texas Department of Transportation (TxDOT) began using an ultra-low sulfur diesel fuel, Texas Low Emission Diesel (TxLED), in all of its diesel engines in the fall of 2003. No problems were encountered with any of these engines except that all ten propulsion engines used in the ferries operated by TxDOT's Galveston Ferry Operations (GFO) failed within about six months after switching to TxLED. TxDOT operates other ferries elsewhere, and none of the propulsion engines used in those ferries experienced any problems. Furthermore, each of the GFO ferries has two other diesel engines that are used for auxiliary power generation, and none of those diesel engines experienced any problems. Therefore, Project 0-5532 was awarded to the Center for Transportation Research (CTR) at the University of Texas (UT) to investigate, determine the root cause of the failures, and recommend solutions.

The research team conducted two rounds of tests of engine oils as a potential solution to these engine failures. The oils tested during the first round of testing were all approved by the engine manufacturer, ElectroMotive Diesels (EMD), with one exception. This unapproved oil contained zinc dithiophosphate (ZDP). This oil was chosen to examine the effects of a synthetic oil with a low ash content. EMD does not approve oils that contain zinc because some EMD engines have silver-coated thrust bearings, and zinc attacks silver. However, the EMD 12-645E engines used for propulsion in the GFO ferries do not have silver-coated thrust bearings. It is suspected that EMD has a blanket disapproval for zinc-containing oils simply to avoid confusion for fleets that have a variety of EMD engines. ZDP is a powerful anti-oxidant and anti-wear additive and there is no scientific rationale for not approving oils with this important additive for use in the EMD 12-645E engines. The research team on Project 0-5532 determined that changing the oil to a type that is more oxidatively stable with lower levels of calcium should provide an immediate low-cost solution. Additionally, none of the GFO engines is still under warranty. Also, the oil containing ZDP was tested during sea trials on one of the GFO ferries and did not cause any problems. For these reasons, it was decided that a second round of oil tests should be performed to include oils that may not be EMD approved but that have properties that could make them beneficial for the GFO application.

During the initial round of oil tests, in addition to the sea trials of the candidate oils, "rapid screening" tests were also performed at UT. A single-cylinder Yanmar diesel engine was modified to produce a high oil consumption rate by increasing the piston ring end gaps. Additionally, this engine was operated under conditions that promote oil consumption: low speed and low load. The tests performed at UT were essential because of the extreme difficulty of obtaining accurate deposit data from the ferry engines. Additionally, obtaining accurate oil consumption data from the sea trials was not possible either. Due to the problems obtaining accurate data from the sea trials, all of the second round testing was performed via the UT rapid screening tests. For the second round of tests, the oil analyses were performed at Southwest Research Institute. This report presents the findings of the tests on the oils selected for the second round of testing.

Prof. Ron Matthews, who is Head of the General Motors Foundation Engines Research Labs at UT, was the Research Supervisor for Project 0-5532. He was assisted by Prof. Matt Hall, Associate Head of the General Motors Foundation Engines Research Labs. Clark Kibler, of Kibler Technologies, was a subcontractor who played an essential role in the oil tests. He is an authority on engine failure analyses, especially those related to the engine lubricating oil. Kibler Technologies primary responsibility on Project 0-5532 was to specify the oils that should be subjected to testing and to aid in the analyses of the results from the oil tests.

The second round of oil tests is discussed in Section 2. Section 3 is a summary of the second round of oil tests and the conclusions that can be drawn from them.

2. Final Round of Lube Oil Tests

Table 1 lists the five oils that were selected for the second round of testing. New commercial diesel engine oil formulations are being introduced to reduce volatility, reduce zinc levels (for increased exhaust catalyst life), and enhance oxidation stability. Additionally, many of these new oils are multi-grade, such as 10W30 and 15W40, and were identified as oils that will lower oil consumption rates. They also contain ZDP, but at lower levels than was previously common. These oils are lower in ash (to increase the life of diesel particulate filters used on trucks that must meet 2007+ heavy-duty emissions standards) and could result in lower rates of deposit formation. Therefore, two of the oils chosen for the second round of testing were oils that are approved for 2007+ heavy-duty diesel trucks: Chevron DELO 400 and Exxon XD-3. The third oil chosen for the second round of testing was an ashless multi-grade aircraft piston engine oil: Exxon Elite 20W50. Aircraft piston engine oil is designed to generate minimum ash in combustion chambers and on exhaust valves while still providing protection of internal engine parts and maintaining cleanliness. The final oil selected for the final round of tests was a single viscosity grade premium natural gas compressor engine oil: Mobil Pegasus 710. This oil has a low ash content and is commonly used in 4-stroke stationary natural gas engines. Finally, Shell Caprinus XR 40 was one of the best oils examined in the first round of tests and it was decided to examine this oil again to serve as a control for the second round of tests.

Table 1. Oils Selected for the Second Round of Tests*.

Oil	**Viscosity Grade**	**TBN/%ash**	**Comments**
Chevron DELO 400	15W40	10.2/1.35	2007+ diesel truck oil
Exxon XD-3	15W40	10.0/1.10	2007+ diesel truck oil
Exxon Elite	20W50	13.5/~0	aviation piston engine oil
Mobil Pegasus 710	40	6.5/0.94	stationary natural gas compressor engine oil
Shell Caprinus XR 40	20W40	13.6/1.46	repeat oil from 1st round

*All are mineral oils, and none are EMD-approved except the Shell Caprinus XR 40

The candidate oils were assessed using three criteria: 1) the rate of accumulation of calcium deposits within the cylinder, 2) the rate of change of wear metals in the oil, and 3) the oil consumption rate. Of these, the calcium deposit accumulation rate is the most important criterion and the oil consumption rate is the second most important criterion.

Figure 1 compares the rate of accumulation of calcium deposits for the five oils examined during the final round of tests. The four new candidate oils have a much lower rate of accumulation of calcium deposits than the Shell Caprinus (which, in the first round of tests, had a calcium deposition accumulation rate that was more than three times lower than the re-refined oil that played a key role in the engine failures). From the calcium deposit perspective, Exxon Elite 20W50 aviation reciprocating engine oil is clearly the best candidate oil.

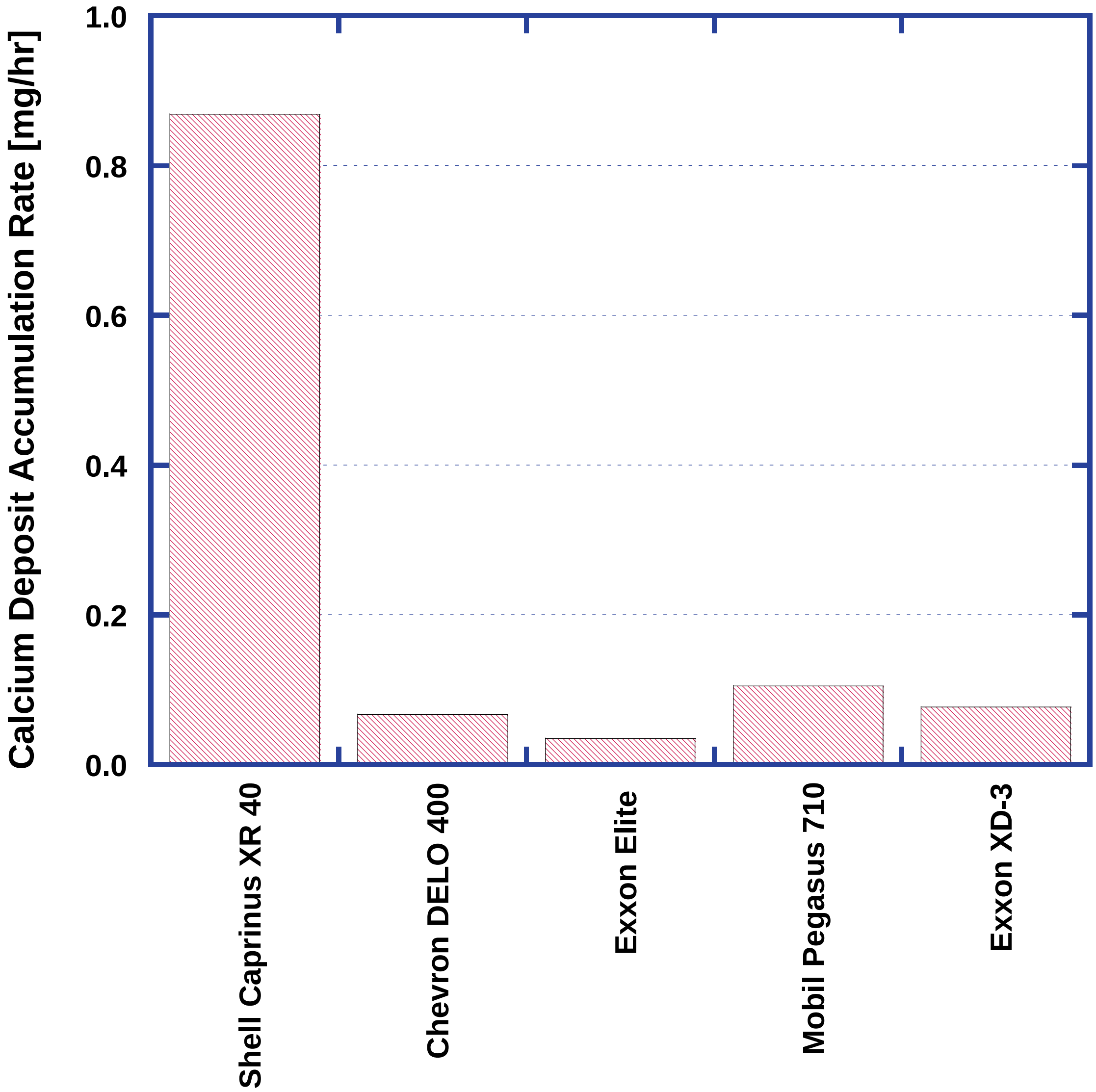

Figure 1. Effect of lube oil formulation for the oils tested in the final round of tests on the rate of calcium deposit accumulation within the cylinder.

Figure 2 illustrates the effects of the oil on the wear metals in the oil. Two of the oils selected for the second round of testing are clearly superior from this perspective:

Chevron DELO 400 15W40 diesel truck engine oil and Exxon Elite 20W50 aviation reciprocating engine oil.

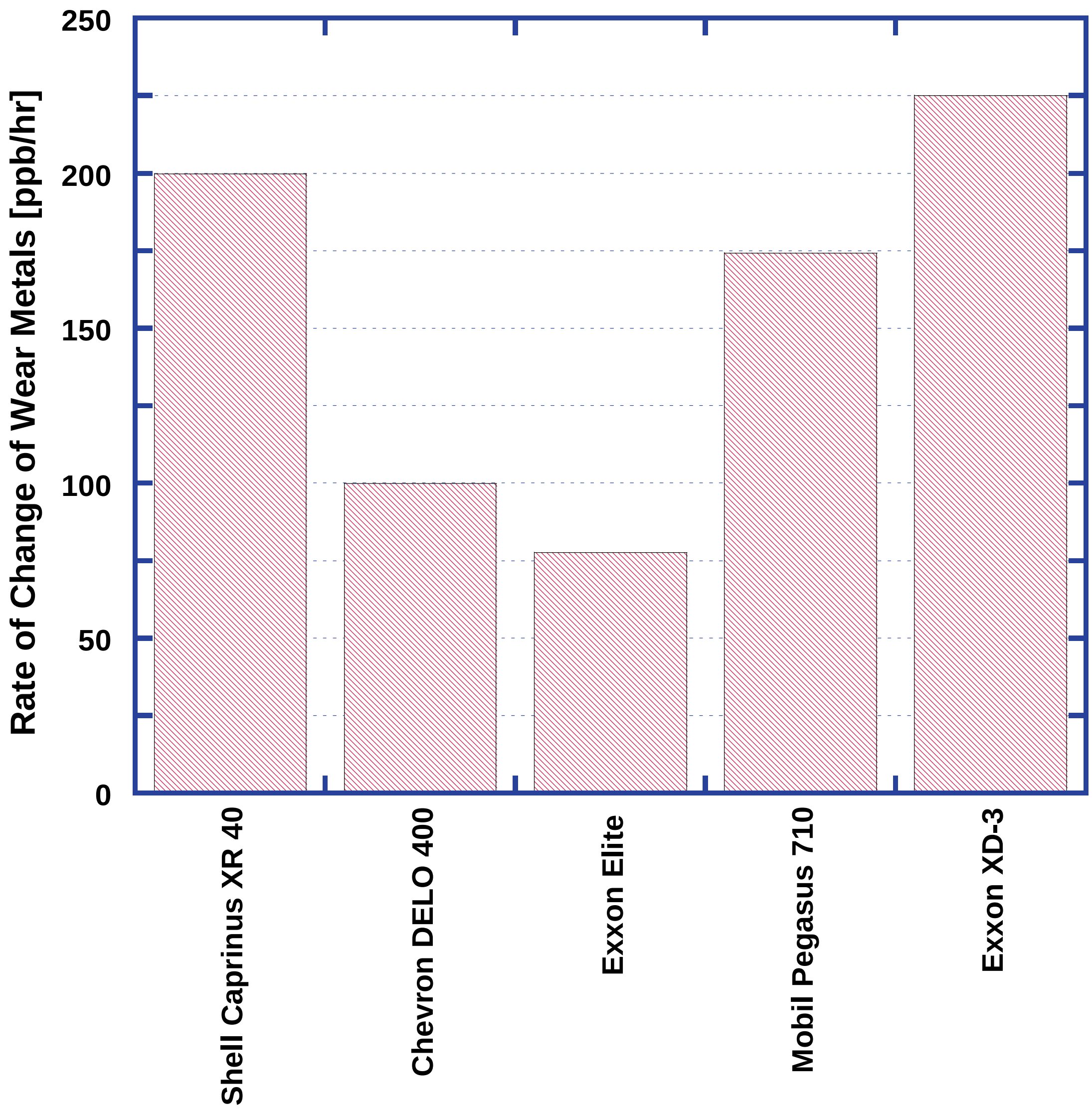

Figure 2. Effect of lube oil formulation for the oils tested in the final round of tests on the rate of change of wear metals in the oil.

The effect on oil consumption is illustrated in Figure 3. The control oil for the second round of tests, Shell Caprinus, was one of the best two oils during the first round of testing from this perspective. All four of the new oils selected for the second round are better than the Shell. One of the new oils from the second round (Exxon XD-3) is superior to all of the other candidate oils from the perspective of oil consumption. Exxon Elite and Mobil Pegasus 710 are the next best oils.

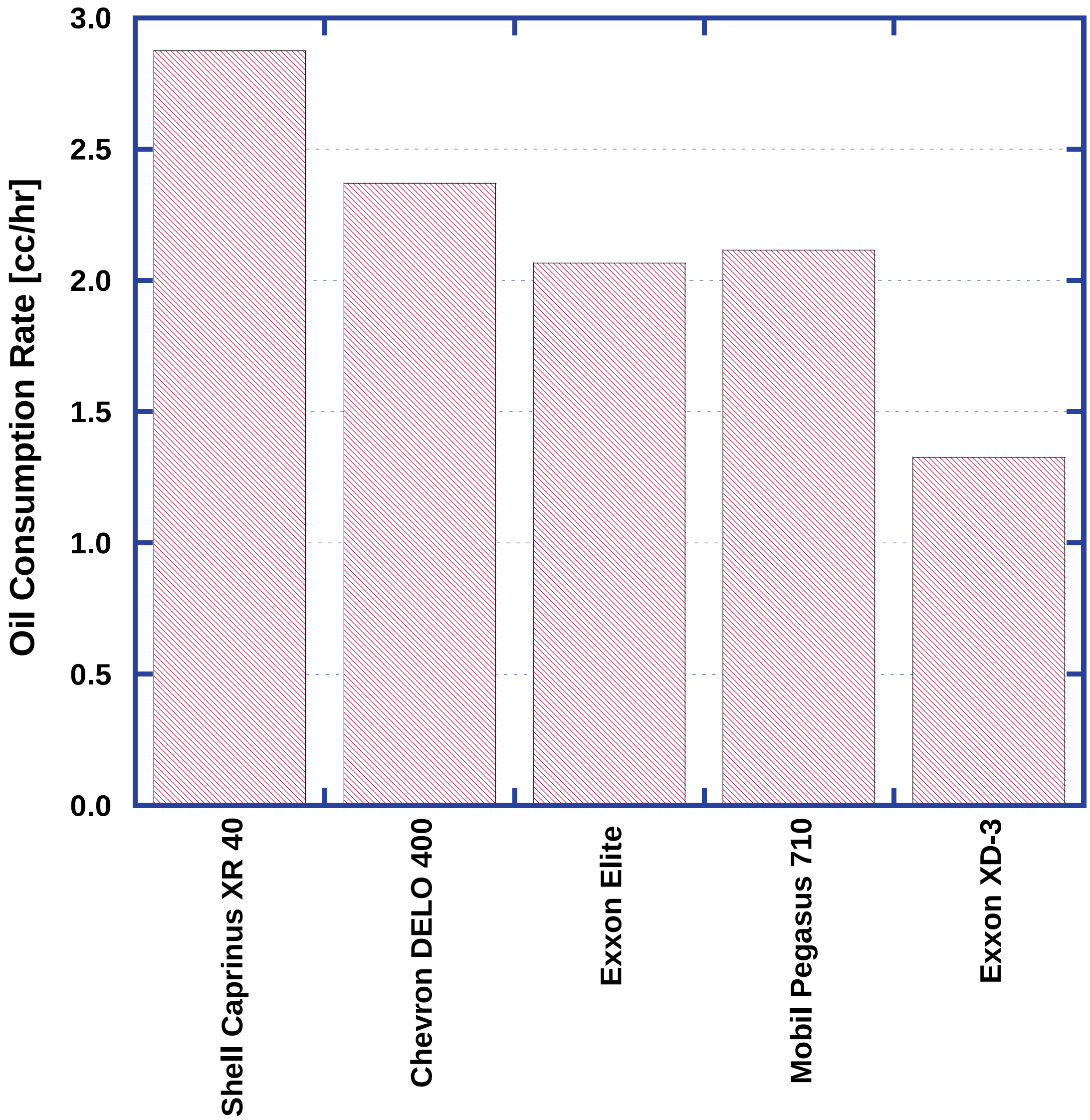

Figure 3. Effect of lube oil formulation for the oils tested in the final round of tests on the oil consumption rate.

3. Summary and Conclusions from the Final Round of Oil Tests

Following the failures of all ten propulsion engines used at TxDOT's Galveston Ferry Operations within months after switching from 2D on-road diesel fuel to an ultra-low sulfur diesel fuel (Texas Low Emissions Diesel, TxLED), the University of Texas was awarded a contract to determine the root cause of the engine failures and to develop a solution that allowed continued use of TxLED.

The research team conducted two rounds of tests of engine oils as a potential solution to these engine failures. The oils tested during the first round of testing were all

EMD-approved, with one exception. This unapproved oil contained zinc dithiophosphate (ZDP) and was chosen to examine the effects of a synthetic oil with a low ash content. EMD does not approve oils that contain zinc because some EMD engines have silver-coated thrust bearings, and zinc attacks silver. However, the EMD 12-645E engines used for propulsion in the GFO ferries do not have silver-coated thrust bearings. ZDP is a powerful anti-oxidant and anti-wear additive and there is no scientific rationale for not approving oils with this important additive for use in the EMD 12-645E engines. The research team on Project 0-5532 determined that changing the oil to a type that is more oxidatively stable with lower levels of calcium should provide an immediate low-cost solution. Additionally, none of the GFO engines is still under warranty. Also, the oil containing ZDP was tested during sea trials on one of the GFO ferries and did not cause any problems. For these reasons, it was decided that a second round of oil tests should be performed to include oils that may not be EMD approved but that have properties that could make them beneficial for the GFO application.

The research team evaluated five candidate oils during the final round of tests. These oils were evaluated based upon their effects on the oil consumption rate, engine wear, and in-cylinder calcium deposits. Four new oils were evaluated during the final round of tests and one of the best oils from the first round was examined again during the second round as a control oil. None of the four new oils (Exxon XD-3, Exxon Elite, Mobil Pegasus 710, and Chevron DELO 400) are EMD-approved. Again, EMD approval is not required because none of the GFO engines is still under warranty, and EMD’s requirement for a zinc-free oil should never have been applied to the EMD 12-645E engines used in the GFO ferries because they do not have any silver-coated bearings.

The research team recommends that Galveston Ferry Operations begin using Exxon Elite 20W50 in all of its ferries. Although this is an airplane piston engine oil, aircraft oils are necessarily designed to minimize wear due to the danger resulting from an engine failure at altitude. Thus, it was not surprising that this oil had the lowest rate of change of wear metals of all of the oils tested. Additionally, like all aviation piston engine oils, Exxon Elite has no ash whatsoever. Thus, it was also not surprising that Exxon Elite also had the lowest rate of accumulation of calcium deposits. Exxon Elite also had the second lowest oil consumption rate.