Mark Riechers
11-10-4

Testimony of Mark Riechers, Director of Regulatory Development for Mercury Marine before the California Air Resources Board regarding the Public Hearing to Consider the Proposed Amendments to California's Small Off- Road Engine and Tier 4 Off- Road Compression Ignition Engine Regulations and Test Procedures; and Amendments to the Exhaust Emission Certification Test Fuel for Off-Road Spark Ignition Engines, Equipment and Vehicles

Good morning/afternoon. My name is Mark Riechers and I am the Director of Regulatory Development for Mercury Marine. Mercury Marine is the largest marine engine company in the world, producing outboards, inboards, sterndrives, water jet engines and diesels. In addition, we are a division of Brunswick Corporation, the largest boat builder in the world. We are the last American owned outboard engine company.

We have also taken a more collaborative approach to new marine engine regulations in recent years. We completed a research project, cofunded by the Air Resources Board, to conduct the proof of concept of catalyst equipped outboard engines, and we are in process of the second phase of this project, also cofunded by the ARB, to evaluate full useful life durability and concepts for reducing emissions on very small outboards.

With regards to the issue at hand, Mercury Marine does not fundamentally disagree with ARB's intention to require certification on a fuel that is more closely aligned with fuels on the market. What concerns us is that the numerous issues that have been identified with Ethanol fuel blends clearly show that it is not necessarily the optimal choice. Ethanol fuels absorb water, can phase separate, can cause corrosion in fuel systems, and negatively affects seals, gaskets, and polymers in the fuel system. There are other bio derived fuels on the near and long term horizon that may make more sense.

While the ARB is only considering E10 at this time, EPA has moved forward with a very misguided approval for E15. The E15 testing that Mr. McKnight alluded to in his comments, much of that testing was done by us. This project was cofunded by the Department of Energy through the National Renewable Energy Laboratory. I can summarize the results in one sentence. We damaged engines on E15. You will be provided photos of some of the damage.

In the near term, biobutanol seems to show much promise. Making it is very similar to making ethanol. However, it does not have most of the negative attributes that ethanol has, has a higher energy content, and can be blended at 16.1% while achieving the same oxygen content as E10. Two companies are building pilot production facilities now. The companies are Gevo and Butamax. Butamax is a joint venture of two companies I am sure you have heard of … Dupont and BP.

Mercury Marine is in the process of developing a Cooperative Research and Development Agreement with the United States Coast Guard to test biobutanol blends in Coast Guard Vessels. The Coast Guard believes that biobutanol is a better alternative to ethanol.

Further down the development line are bio derived "drop in" fuels. These are fuels, derived from biomass, that are so similar to fuels currently in use that the infrastructure and the engines would not know the difference. There are over 30 companies working on these currently, including major chemical companies.

The bottom line is that we would suggest that ethanol blended fuels may not be the fuel of choice by the time this comes into force. We would like to suggest a couple of options, one that Mr. McKnight suggested is that it be based on the oxygen content of the fuel and not the actual oxygenate utilized in the blend, and secondly, we request that the Board instruct staff to review the real world of fuels and biofuels every couple years and, if the state of development of some of these alternatives dictates it, come back to the Board and propose appropriate modifications.

Mercury Marine thanks you for this opportunity to address the Board and share our thoughts on this very important and rapidly changing issue.

High Ethanol Fuel Endurance Advanced Engineering Project

A study of the effects of running 15% ethanol concentration in current production 4-stroke engines and "legacy" 2-stroke engines.

Prepared By:

Dave Hilbert

BRUNSWICK
GENUINE INGENUITY

Overview

This project is a cooperative effort to assess the feasibility of increasing the allowable ethanol concentration in gasoline above the current legal limit of 10% for use in marine engines.

- **Objectives of this project:**
  - Run 300 hours of wide-open throttle endurance on 3 engine families and measure emissions at 0, 150, and 300 hours.
    - 9.9HP 4-stroke carbureted, 200HP 2.5L 2-stroke EFI (represents "legacy" product) and 300HP L6SC Verado engines were chosen.
    - Two engines from each family
      - Test engine operated on E15
      - Control engine run on pure gasoline

Test Engine Specifications

	9.9HP 4-Stroke	Verado	200 EFI
Gas Exchange Process	Four Stroke	Four Stroke	Two Stroke
Power Rating at Prop	9.9HP	300HP	200HP
Cylinder Configuration	Inline 2 Cylinder	Inline 6 Cylinder	60 Degree V-6 Cylinder
Displacement	0.209 Liter	2.59 Liter	2.51L
Fuel Induction System	Single Carburetor w/Accelerator Circuit, 2 Valve per Cylinder, Single Overhead Cam	Supercharged Electronic Fuel Injected 4 Valve per Cylinder, Dual Overhead Cam, Electronic Boost Control, Electronic Knock Abatement Strategy	Electronic Fuel Injected with Oil Injection, Loop Scavenged Porting, Crankcase Reed Induction, Electronic Knock Abatement Strategy
Dry Weight	108 lbs / 49 kg	635 lbs / 288 kg	425 lbs / 193 kg
Fuel Requirement	87 Octane R+M/2 Minimum Required	92 Octane R+M/2 Recommended, 87 Octane R+M/2 Minimum Required	87 Octane R+M/2 Minimum Required

Results Summary

- **Verado**
  - Initial E15 engine generated HC+NOx emissions in excess of FEL when operated on E15 fuel.
  - E15 engine failed exhaust valves. Metlab analysis showed excessive metal temperatures caused a reduction in fatigue strength.
- **F9.9HP**
  - The E15 engine on E15 fuel showed high HC variability at the post-endurance emissions testing. It is believed that this engine was misfiring at idle due to the lean operation.
  - The E15 engine showed evidence of hotter metal temperatures due to carbon deposits, etc.
  - The E15 engine showed signs of gasket deterioration on the fuel pump.
- **200HP EFI 2.5L 2 Stroke**
  - E15 engine showed no difference in emission deterioration.
  - E15 engine failed the rod bearing. Root cause is indeterminate due to the degree of damage.
    - How does ethanol affect oil dispersion in two stroke engines?
  - Other than the bearing failure, the end of test teardown and inspection did not show any significant difference between the 2 engines

Results Summary-Continued

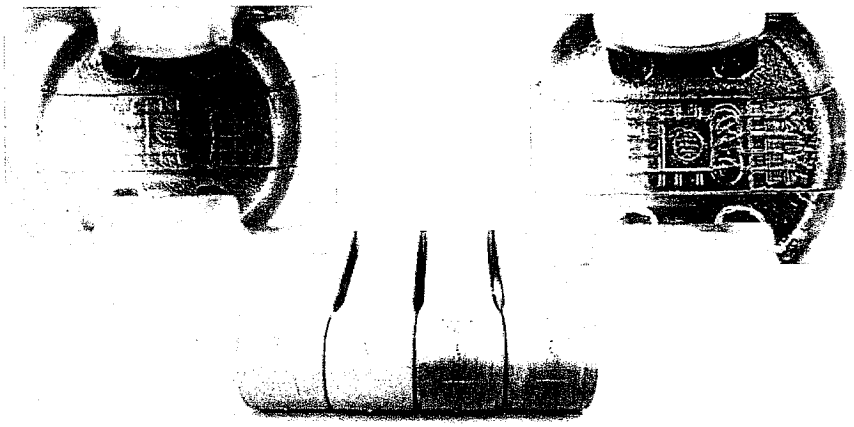
- **4.3L V6 ECT Mercruiser**
  - Two emissions tests were performed on a 4.3L catalyzed sterndrive engine to compare the E0 fuel and the E15 fuel. No durability testing was completed on the 4.3L engine with E15 fuel.
  - This testing was not part of the contract, but was performed due to the fact that the E15 test fuel and a catalyzed engine were readily available on the dyno. Also, it compliments the testing on a 4.3L carbureted engine done by Volvo Penta.
  - EGT increased ~20C and catalyst temperatures increased ~32C at Mode 1 (WOT).
    - Valvetrain durability and catalyst system deterioration concerns.
  - Fuel consumption increased by ~5% (mass-based fuel flow) in closed loop operation.
  - Aside from HC and CO reductions at Mode 1 (open loop), the E15 fuel afforded no real benefit to reduced emissions overall.
    - NOx increased at Mode 1, but not as much as HC decreased for a slight overall reduction.
    - HC, NOx and CO in closed loop operation are essentially unchanged between the 2 fuels.
- **Overall**
  - The CO emissions were lower on all engines with E15 fuel due to leaner running (as would be expected).
  - Fuel analysis showed the E15 fuel that was used in testing was in line with expectations.

Conclusions and Recommendations Summary

- **Despite the limited scope of project several significant issues were discovered.**
  - Durability Failures
  - Emissions Issues (elevated NOx, HC variability)
  - Run Quality due to Lean Operation
- **More testing is necessary to understand effects on:**
  - Driveability- Ex. cold and hot start, transient accel/decel, "boiloff", etc.
  - Oil dispersion in 2 stroke engines
  - Storage (phase separation, corrosion, etc.)
- **Test program was a cursory look at the effects of E15.**
  - Sample size was insufficient to have statistical significance.
  - WOT operation only-masks effects of true customer duty cycle

F9.9HP 4-Stroke Teardown and Inspection

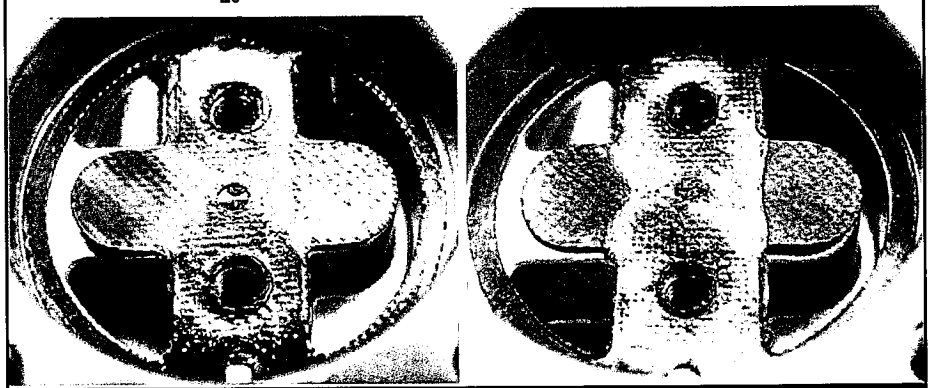
- More carbon deposits on piston undercrown and rods of E15 engine.



F9.9HP 4-Stroke Teardown and Inspection

- The gasket showed signs of deterioration on the E15 engine compared with the E0 engine.
- The gasket on the E15 engine had a pronounced ridge formed in the area that "hinges" when the check valve is in operation
- The E15 gasket material in the area that seals the check valve also had signs of wear that were more advanced than the E0 gasket.

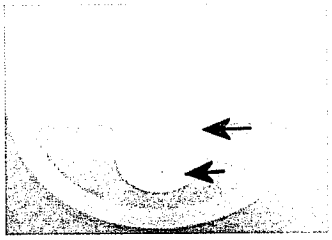
E0 E15



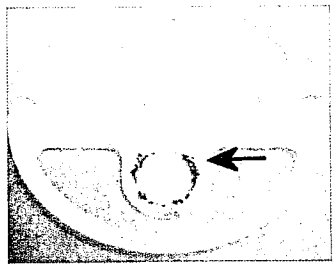
F9.9HP 4-Stroke Teardown and Inspection

- Material transfer from gasket to diaphragm in mechanical fuel pump.

E0

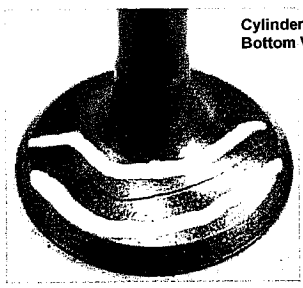


E15

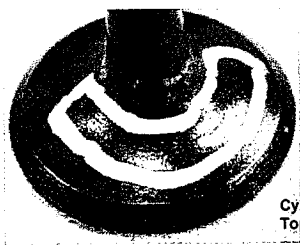


Verado E15 Valve Failure Investigation

Cylinder 3
Top Valve

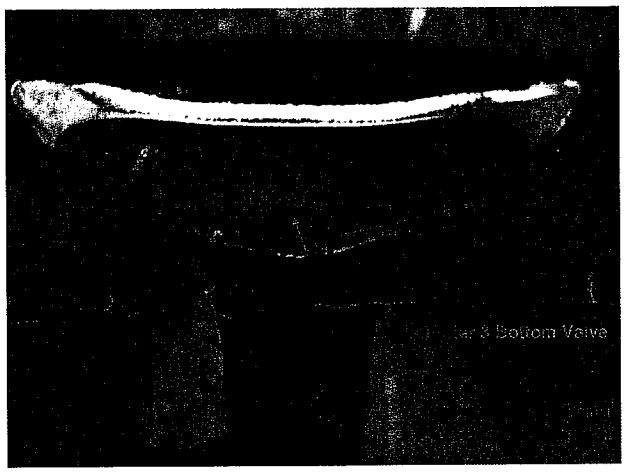


Cylinder 3
Bottom Valve



Cylinder 6
Top Valve

Verado E15 Valve Failure Investigation

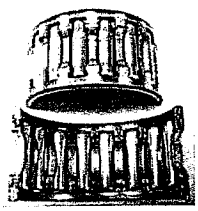


200HP EFI E15 Engine-Bearing Failure

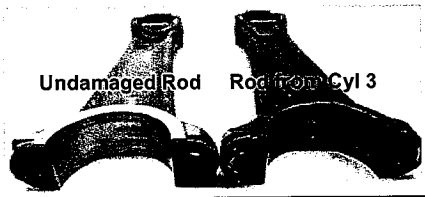
- Root cause of bearing failure is unknown.
- 283 total engine hours, 256 WOT endurance hours
- No rollers were recovered.

Remaining Pieces from Cyl 3 Rod Bearing Cage

Undamaged Bearing



Undamaged Rod



Rod from Cyl 3