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Review of Certificates of Analysis and Test Data of Aviation Gasoline for Current Ranges of Lead Additive

Assessing the Viability of Producing Lower-Lead Fuels in Current Aviation Gasoline Production

October 2011

DOT/FAA/AR-TN11/20

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-TN11/20		

4. Title and Subtitle	5. Report Date
REVIEW OF CERTIFICATES OF ANALYSIS AND TEST DATA OF AVIATION GASOLINE FOR CURRENT RANGES OF LEAD ADDITIVE ASSESSING THE VIABILITY OF PRODUCING LOWER-LEAD FUELS IN CURRENT AVIATION GASOLINE PRODUCTION	October 2011
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
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	11. Contract or Grant No. DTFAWA-08-C-00009 (NISC II Bridge)
12. Sponsoring Agency Name and Address	13.Type of Report and Period Covered
U.S. Department of Transportation Federal Aviation Administration Air Traffic Organization NextGen & Operations Planning Office of Research and Technology Development Washington, DC 20591	Technical Note
	14.Sponsoring Agency Code ANE-111

15 .Supplementary Notes

16. Abstract

The general aviation gasoline user community has established a goal to reduce the amount of lead added to current aviation gasoline. This endeavor evaluated lead additive levels in commercially available aviation gasolines currently meeting the ASTM D 910 specification for 100 low lead. Certificates of Analysis were procured for contemporary loads of aviation fuels from a variety of fixed-base operators (FBO) and test laboratories, as well as fuels used by engine manufacturers for engine certification. Also, fuel samples were purchased from various FBOs and sent to laboratories for full specification properties analyses. A sample set of 83 individual data points were reviewed for the lead content (converted to grams of lead per liter of fuel), motor octane number (MON) per ASTM D 2700, and supercharge performance number per ASTM D 909. The samples were also segregated by regions using time zones of the manufacturer location, and by refinery (blinded for this report) in an attempt to identify, if any, relationships by region or by refiner. From this sample set, 43% of the fuels had lead contents that were more than 20% below the maximum allowable lead content. No strong correlation between lead level and MON was found. More than 95% of the fuels had MONs greater than 102 per ASTM D 2700.

17. Key Words	18. Distribution Statement
100LL, Certificates of Analysis, Low lead, Very low lead, ultra low lead, AvGas, Aviation, Gasoline, Piston fuel, Aircraft, Motor octane number, Supercharge, Refiner, Fixed-base operators, General aviation	This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	19	

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LIST OF ACRONYMS

AvGas	Aviation gasoline
CoA	Certificate of Analysis
FBO	Fixed-based operators
gPb/L	Grams of lead per liter
gPb/gal	Grams of lead per gallon
MON	Motor octane number as determined by ASTM D 2700
NEG	National Exchange Group
TEL	Tetraethyl lead
ULL	Ultra low lead

EXECUTIVE SUMMARY

This research surveyed Certificates of Analysis (CoA), sample fuels procured from fixed-base operators, and engine test data for lead content in an attempt to facilitate the reduction in lead levels from current aviation gasoline. Survey data of lead content of 100 low-lead aviation gasoline CoAs, ASTM National Exchange Group (NEG) data, and engine manufacturer's reports were used without change or prejudice. CoAs are accepted by the industry as certificates of validation. Further investigation or verification of the accuracy of the reported data was determined to be outside the scope of this research.

The sample set included 83 individual data points that consisted of the collection of CoAs from fixed-base operators, CoAs from independent laboratories that were performed on a collection of airport fuel samples, engine manufacturers' records for fuels that were used for engine certifications, and from data collected by the ASTM NEG.

It was determined that approximately 43% of the fuel described by the CoA and industry laboratory reports could meet a 20% reduction in the maximum allowable tetraethyl lead (TEL) additive content, 55% could meet a 15% reduction in TEL, and 67% could meet a 10% reduction in TEL, as indicated by current production lots. The mean elemental lead content was 0.46 grams of lead per liter (gPb/L), and the median was 0.48 gPb/L. The maximum was 0.60 gPb/L, and the minimum set was 0.08 gPb/L.

Of the nine engine manufacturers' certification fuels with indicated lead content, 44% could meet a 20% reduction in maximum lead content and 67% could meet a 15% reduction. This is in agreement with fielded data. The mean motor octane number (MON) value was 103.6. The maximum MON was 108, and the minimum MON was 100. Of the 15 engine certification fuel samples, the mean MON value was 103.8, the maximum MON value was 107.6, and the minimum MON value was 101.1.

No conclusions regarding the relationship between fuel composition, MON level above minimum specification requirement, or how the lead reduction will affect the MON values could be made. This analysis should only be used to evaluate the existence of fuels currently meeting ASTM D 910 with less than maximum allowable lead content. Furthermore, the production of 100 very low lead may require more than just a reduction in lead. The data in this report is only a demonstration of the ability of refiners to produce a lower-lead fuel, not an analysis of how to produce fuel with lower lead. Significant research and development may be required by refiners to develop fuel formulations that still meet all the specification requirements in ASTM D 910.

Several data points indicated MON values higher than expected. Although MON is of interest, the primary objective of this survey was to investigate TEL trends in production aviation gasoline. A review of the data by region and by refinery showed no relationship with the amounts of lead used, with the exception of one refinery. While there was limited aromatic information obtained, there did not appear to be any relationship between the lead content and the aromatic content. This is likely due to the influence of the third component, the base alkylate for which there was no information obtained.

INTRODUCTION

BACKGROUND.

In 2010, the Environmental Protection Agency issued an advanced notice of proposed rulemaking regarding lead emissions from piston aircraft engines and requested comment on data availability. Industry stakeholders explored the possibility of reducing the amount of lead used in current, compliant fuel formulations as a near-term goal. Several means for evaluating lead reduction levels were proposed: (1) attain refinery data on the current ability to reduce lead additive levels while still meeting the ASTM D 910 [1] specification, (2) attain blends of ultra-low-lead (ULL) fuel that meet ASTM D 910 and have them tested, and (3) review current Certificates of Analysis (CoA) for fuel supplied to various fixed-base operators (FBO) and assess the actual lead content of current compliant fuels available in the industry.

Attainment and assessment of refinery data on the ability to reduce lead levels proved to be a daunting task. Several of the refiners agreed to blend ULL formulas, but there was considerable disagreement regarding whether the refiners should take current formulas and add less lead and test the result or whether they should adjust the fuel composition to maintain all of the specified properties and risk developing data for noncommercial aviation gasolines (AvGas). The ULL activity was further complicated by the length of time necessary to obtain various blended fuels and complete subsequent testing.

A review of CoAs for currently supplied fuel was performed. Representatives from the Federal Aviation Administration William J. Hughes Technical Center requested and collected CoAs from a random selection of FBOs. In some cases, fuel samples were collected from the FBOs and specifically analyzed by an independent laboratory. In addition to the data collected from FBO fuels, the laboratory analyses from the certification fuels used by the engine manufacturers and data from the ASTM National Exchange Group (NEG) analyses were collected. This data was compiled and then analyzed. This report documents the findings of this analysis.

DISCUSSION

SAMPLE HANDLING.

Copies of the CoAs were collected from the FBOs where the fuel was purchased. The FBOs were randomly selected, and the data from the certificates were entered into a spreadsheet. For those fuels collected from the FBOs, the laboratory data sheets were used as a data source. The data was entered as provided; no entries were made when data was not provided. For the motor octane number (MON) and lead content values, each sample had its refinery identity blinded so the data could be sorted based on the refinery without identifying the refiners in the data set.

REGION IDENTIFIER.

Each refinery was given a regional identification number by using the U.S. time zone based on the location of the refinery. In some cases, the location of the refinery was overtly provided. In other cases, it was inferred based on the primary location of a company's refinery. For example, one company had two locations at which they produce AvGas, both in the same time zone.

Thus, any sample from this company could reasonably be placed in single time zone. Each location was given a number based on the time zones shown in figure 1. A small number of global AvGas samples was coded as "global."

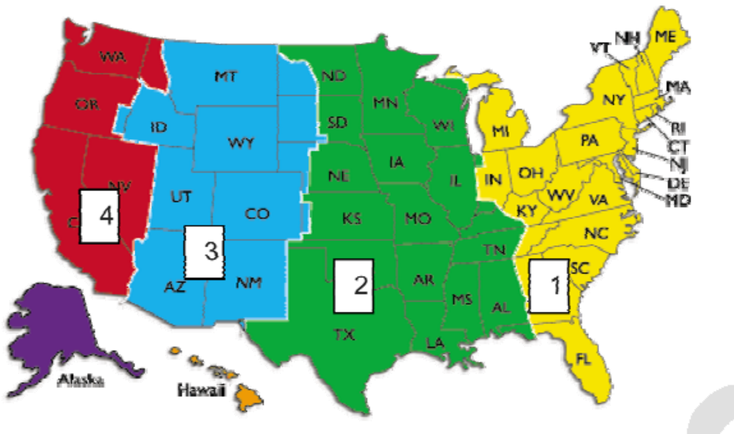

Figure 1. U.S. Time Zones

The sample set included 83 individual data points. While the sample set was small, data analysis suggests that it was representative of the East Coast (Zone 1) and Midwest (Zone 3). There were no obvious indications that it was not representative of Central (Zone 2) and West Coast (Zone 4).

THE MON VALUES FROM AVIATION LEAN RATINGS.

Some of the CoAs provided the octane performance as aviation lean ratings. These were converted to MON using Table 9 from ASTM D 2700-09 [2]. The aviation lean rating was found on the table and the equivalent MON was read from the axes. When necessary, the value was interpolated.

LEAD CONTENT.

For the purpose of analysis, all the provided lead contents were converted to a uniform unit of grams of lead per liter (gPb/L). For lead contents provided as milliliters of tetraethyl lead (TEL), the conversion factor of 1mL TEL = 1.0589 gPb was used. For those provided as lead in gallons, these values were converted to liters, 1 U.S. gallon = 3.785 liters.

OTHER DATA SOURCES.

In addition to the data from CoAs, data from the ASTM NEG was included as a separate entry. These data were averaged values from a set of samples used to confirm the inter-laboratory repeatability of specification testing. These data were provided as average values with the refinery information purged prior to receipt.

Data were also provided from engine manufacturers from their engine certification tests. An additional set of 15 certificates for fuel used during engine certifications was supplied and reviewed. These data included both generic fuel procured for the test and for specifically blended test fuels. Only the CoAs for the commercial production AvGas were used for the analysis.

<u>DEVELOPMENT OF MAXIMUM LEAD FOR REDUCTION LEVELS</u>.

To assess the maximum reduction level that could be achieved, the maximum lead content for each of three reduction levels was computed. The reductions considered were 20%, 15%, and 10% reduction from current maximum lead content permitted by ASTM D 910. This correlated to lead content maximums of 0.45, 0.48, and 0.51 gPb/L, respectively. For the analysis, the number of individual fuels that would have met the maximum levels was counted and reported. It was assumed that (1) because these were fuels meeting specification, it was an indication that individual refiners could currently produce fuels with the indicated levels that met specification, and (2) the small sample set would replicate the larger population within an acceptable level.

ANALYSIS

<u>COMBINED DATA</u>.

After review of the data sets, it was determined whether there was any observable correlation between the supercharge rating, the MON, and the lead content of the fuel. Figure 2 contains the data from the CoAs, the ASTM NEG, and the engine certification, excluding blended experimental samples.

This analysis was performed to determine if there was any indication of a correlation between observable variations in the supercharge rating and the MON with changes in lead content. No correlations were observed. All MON values were reasonably consistent while the lead values showed observable variations.

In addition to the data, lines indicating the 20% reduction (orange) and the 15% reduction (blue) in the maximum TEL level are included on the graph. This visually indicates the observation that was mathematically calculated that between 33% and 43% of the samples would meet the 20% reduction in maximum TEL content. About 55% of the samples would meet a 15% reduction in maximum TEL content, and 67% would meet a 10% reduction in maximum TEL content. These values remained relatively constant as additional data was included in the data set.

Because refiners have basically three major building blocks with which to achieve the desired MON and supercharge rating (alkylate, lead, and aromatic content), any relationships between the building blocks needed to be evaluated. No information was available for the alkylate type or quality, so the relationship between aromatic content and lead content was evaluated. This is shown in figure 3. Unfortunately, few of the data sheets included a value for aromatic content. For those samples that did, there appeared to be no correlation between the aromatic content and the amount of lead used. In some cases, the lead and aromatic contents were relatively higher together compared to other samples, and in other cases, samples with high lead had low total aromatic content. This was most likely due to differences in the type of alkylate used. No correlation could be drawn between lead and aromatic content from these data.

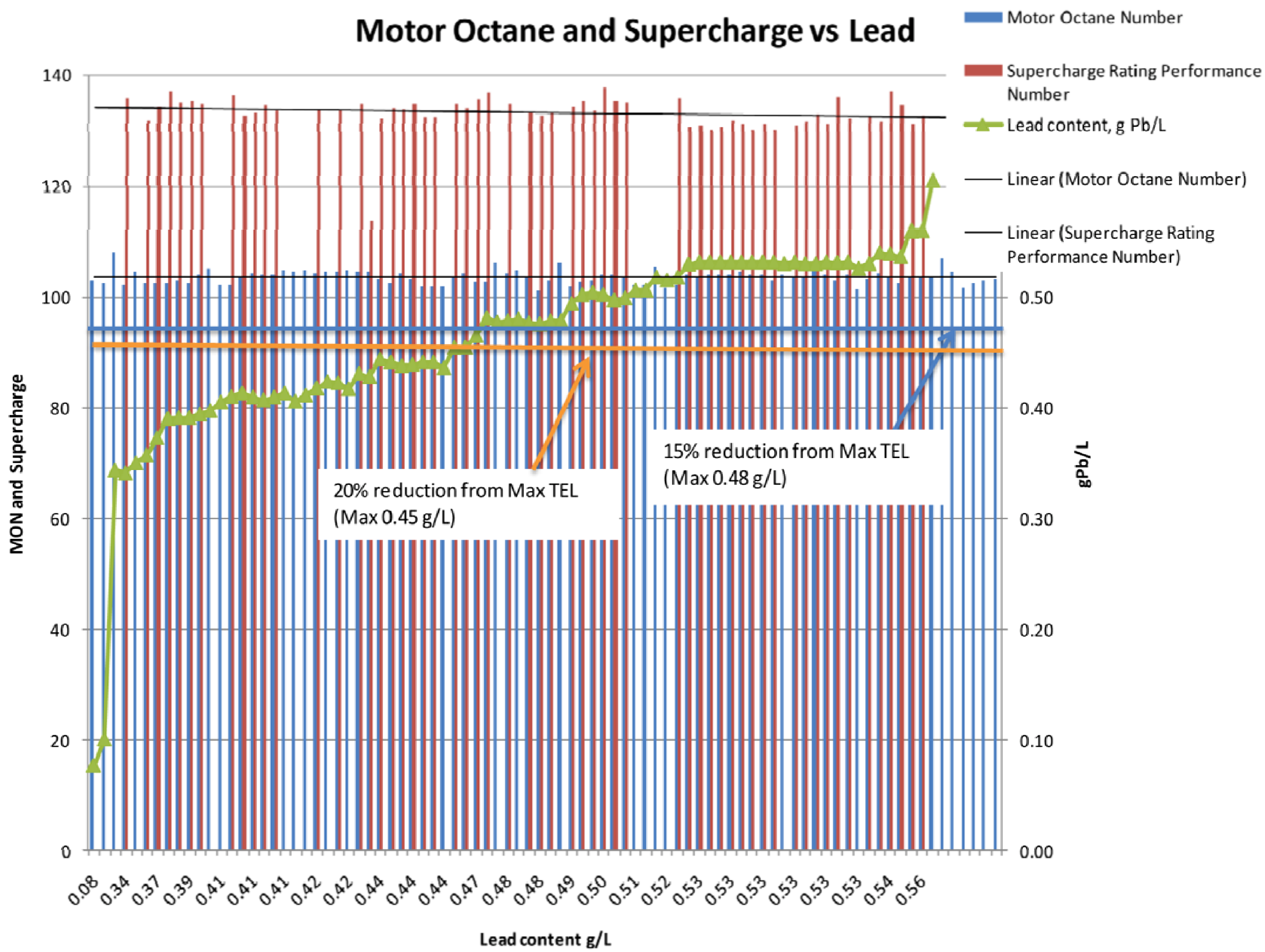

Figure 2. Supercharge Rating and MON vs Lead Content, Including Engine Certification Fuels

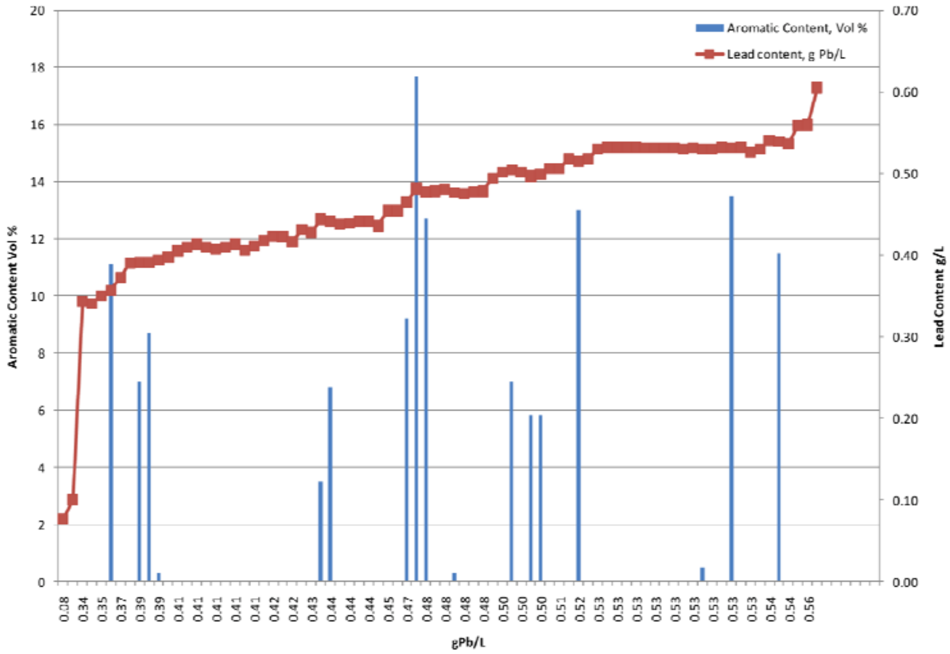

Figure 3. Lead Content vs Aromatic Content, Including Engine-Certified Fuels

The mean lead content of all analyzed samples, excluding blend samples, was 0.46 gPb/L. This value is 82% of the maximum lead level permitted by ASTM D 910 for 100 low lead (0.46/0.56).

Ninety-five percent of the samples reviewed had MON values greater than 102, 85% had MON values greater than 103, and 49% had MON values greater than 104. Only 11% of the samples had MON values higher than 105.

This data set included 23 individual entries for which 21 had a MON entry and 9 had a lead content. Of the 23 samples, 6 were blends prepared from 100LL and iso-octane and were not included in the analysis. This data were analyzed separate from the field sample entries.

<u>BY REGION</u>.

To determine trends based on the region of the country in which the fuel was produced, the data were separated by time zone regions and then sorted. The data were graphed to evaluate lead content versus aromatic content by region, excluding the engine certification data. Because of the method for procuring the data, the majority of the samples that were designated to a region were from regions 1 and 2.

An attempt to identify whether aromatics were used more prevalently in a specific region was also made. Figure 4 shows the data comparing aromatic content to lead content by region. Again, the analysis was hampered by a lack of aromatic content data. Aromatic content data were primarily found in samples that could not be attributed to a region. The three global samples showed higher aromatic content, but these were fuel samples blended specifically to be ULL samples.

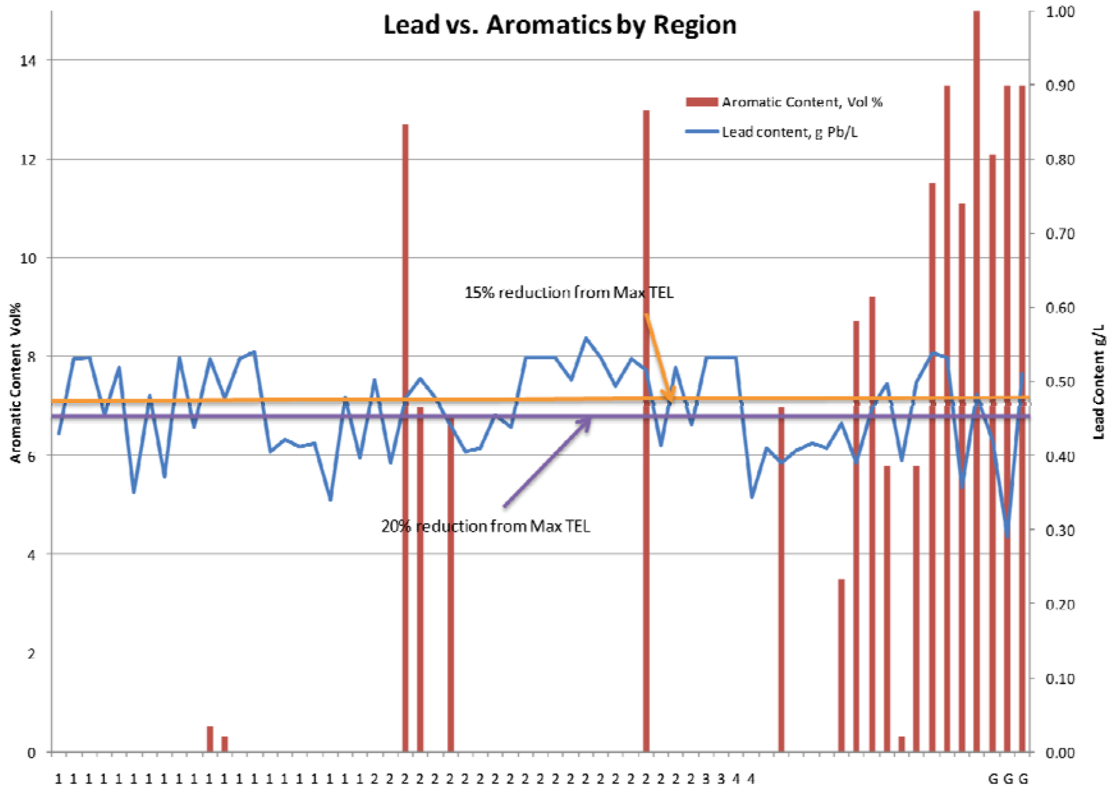

Figure 4. Lead Content vs Aromatic Content by Region for CoAs, Excluding Engine-Certified Fuels

The MON versus lead content is shown in figure 5. In general, there was just as much variability in both the MON and the lead content in regions 1, 2, and 4. Region 3 had similar sample values; however, with only two data points, no conclusion could be reasonably drawn. The data not attributed to a specific region had similar variability. The samples attributed to non-U.S. manufacturers, i.e., global, had 100 MON values, but this was due to being prepared specifically for a ULL test.

Again, no trends were observed in the data by region for either the MON versus lead or the aromatics versus lead, with one possible exception. There appeared to be slightly higher lead used in region 2. This, however, is likely explained by a review of the data by refinery and is presented in the next section.

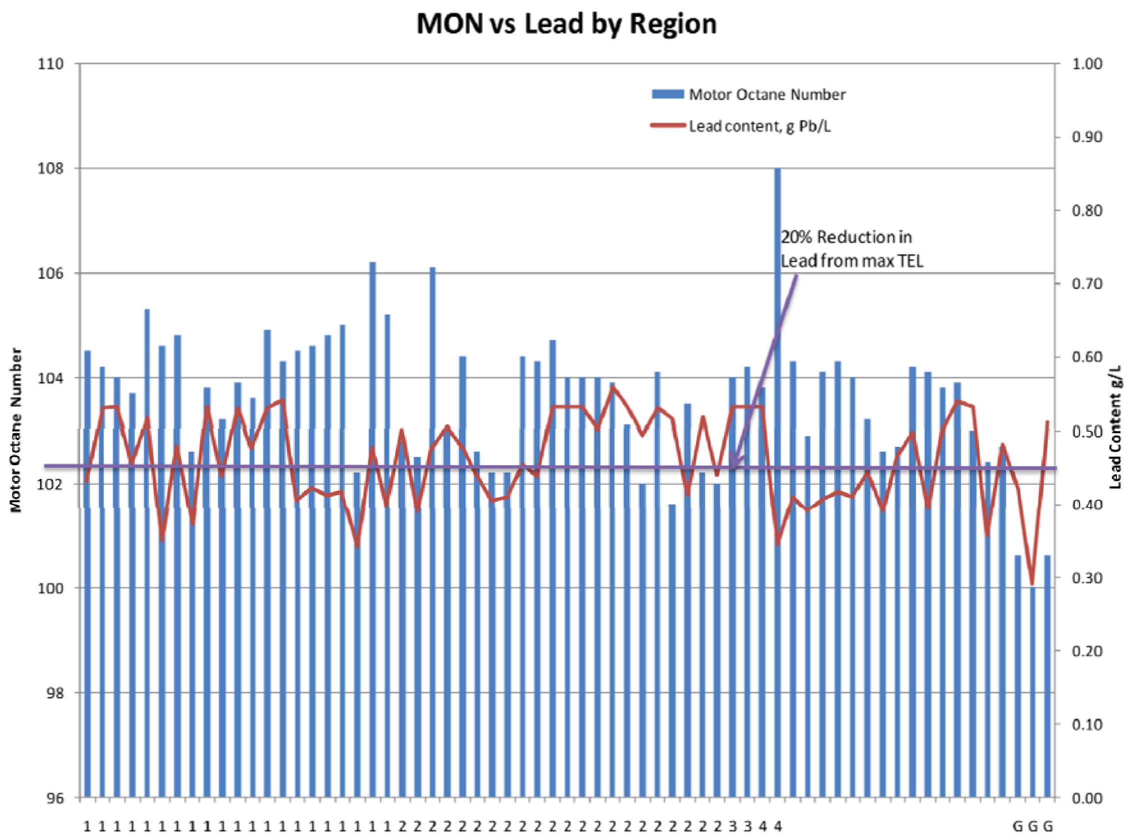

Figure 5. The MON vs Lead Content by Region for CoAs, Excluding Engine-Certified Fuels

BY REFINERY.

A decision to reduce the maximum lead content may result in single refineries being unable or unwilling to continue to produce AvGas. Even if 40% of the refineries sampled are capable of producing specification fuel with lower lead, it is possible that one of the remaining 60% could account for the majority of the AvGas produced. Unfortunately, it is beyond the scope of the data and this report to comment on that risk. It was possible, however, to evaluate the currently produced fuel by the refiner of record on the CoA. This gives no information on the refiner's abilities to produce fuel of a lower-lead content over time, but it does give information on the existence of fuel produced by a refiner with lower-lead contents at individual points in time.

A review of the aromatic content by refiner (shown in figure 6), again, showed too little aromatic data to be of value in drawing conclusions. However, a review of the MON versus lead data, shown in figure 7, indicates that there is a strong correlation in lead content for one of the blinded refineries. The refinery indicated by "H" showed the routine use of nearly maximum TEL. In only one instance was less than 0.45 gPb/L used and that instance correlated to a lower MON content at the same time. For the data set reviewed, this refinery accounted for nearly one-quarter of the fuel samples considered. It is not known if this relationship is comparable to the industry position for the refinery.

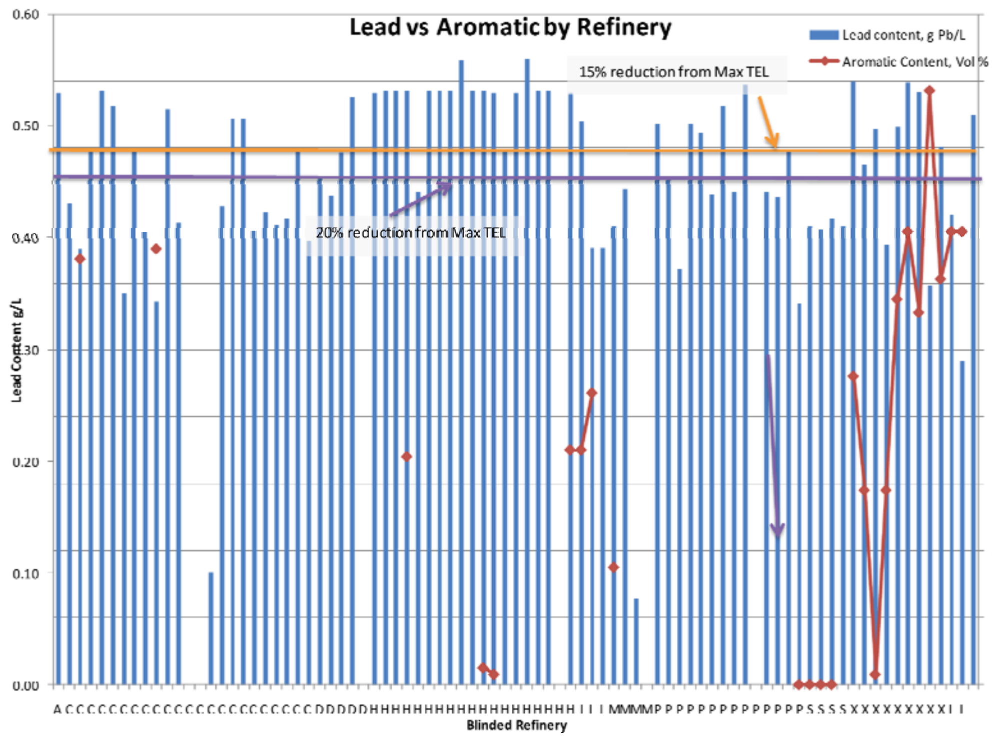

Figure 6. Lead Content vs Aromatic Content by Blinded Refinery, Including Engine-Certified Fuels

Two refineries accounted for just over half of the samples reviewed. When separated by refinery, 23% of the fuel in the sample set was provided by a single refinery. Another 28% was provided by another single refinery. It was determined that only 5% of the CoAs from the first refinery contained less than 20% of the maximum allowable TEL additive (1 of 19 samples). At a reduction of 15%, only 11% of the production from this refinery would be in specification. This is far below the group percentages and indicates that this refinery would likely be unable to meet a lead reduction with current production.

For the refinery that accounted for 28% of the CoAs, the CoAs met a 20% reduction in maximum lead content in slightly more than one-half of the samples (57%), and a 15% reduction in about two-thirds (65%) of the samples.

Further analysis of the use of lead by refinery indicated that two refineries with two and four samples, respectively, could meet the 0.45 gPb/L limit with all their samples. These two refineries only accounted for 9% of all the samples reviewed and accounted for only six samples. A fourth refinery could meet the 15% reduction with all four of their samples.

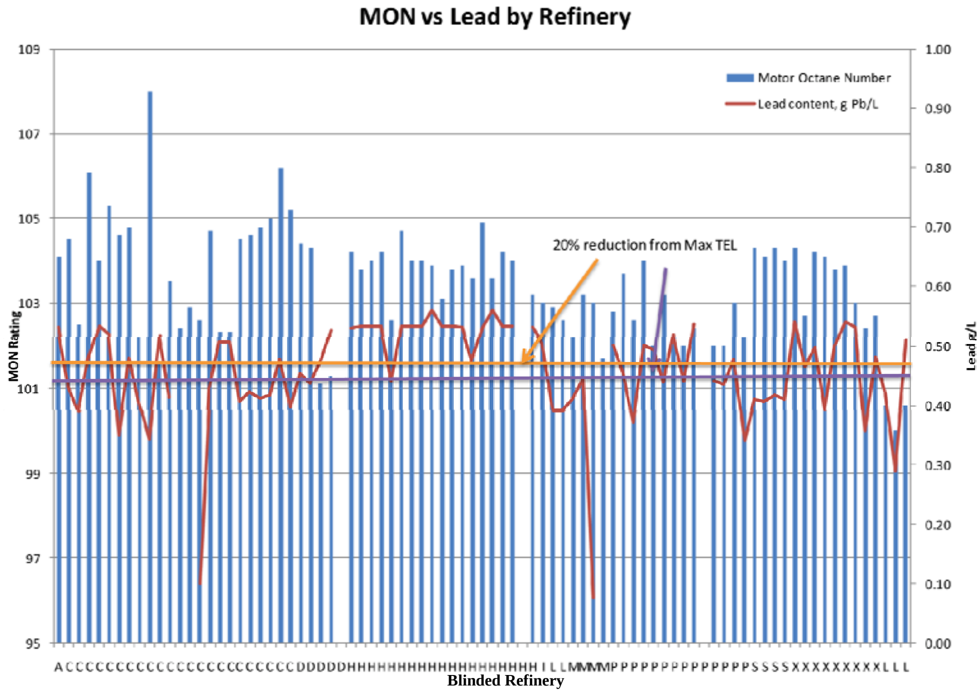

Figure 7. The MON vs Lead Content by Refinery, Including Engine-Certified Fuels

The breakdown of the remaining refineries is shown in table 1.

Table 1. Ability of Refinery to Produce Lower Lead, On-Specification AvGas

No. Samples From Given Refinery	No. of Samples With More Than 0.45 gPb/L	No. of Samples With More Than 0.48 gPb/L	No. of Samples With More Than 0.51 gPb/L	Proportion of Samples That Meet a 20% Reduction in Maximum TEL (% of total refinery samples)	Proportion of Samples That Meet a 15% Reduction in Maximum TEL (% of total refinery samples)	Proportion of Samples That Meet a 10% Reduction in Maximum TEL (% of total refinery samples)	Proportion of Sample set (% of total samples)
23	13	15	18	57	65	78	27.7
5	1	3	3	20	60	60	6.0
19	1	2	2	5	11	11	22.9
2	2			100	100	100	2.4
4	3	3	3	75	100	100	4.8
14	6	8	11	43	57	79	16.9
4	4			100	100	100	4.8
9	2	3	6	22	33	67	10.8

FROM ENGINE CERTIFICATION FUELS.

In addition to reviewing the fuels as an agglomeration, the fuels were also reviewed specific to the data set provided on the fuels used for engine certifications. It was noted that not all data included lead content data; however, all the data, including the blended test fuels, provided MON values or aviation lean rating values that were converted to MON. Of the 15 samples provided, 9 included lead content. These data are shown in figure 8.

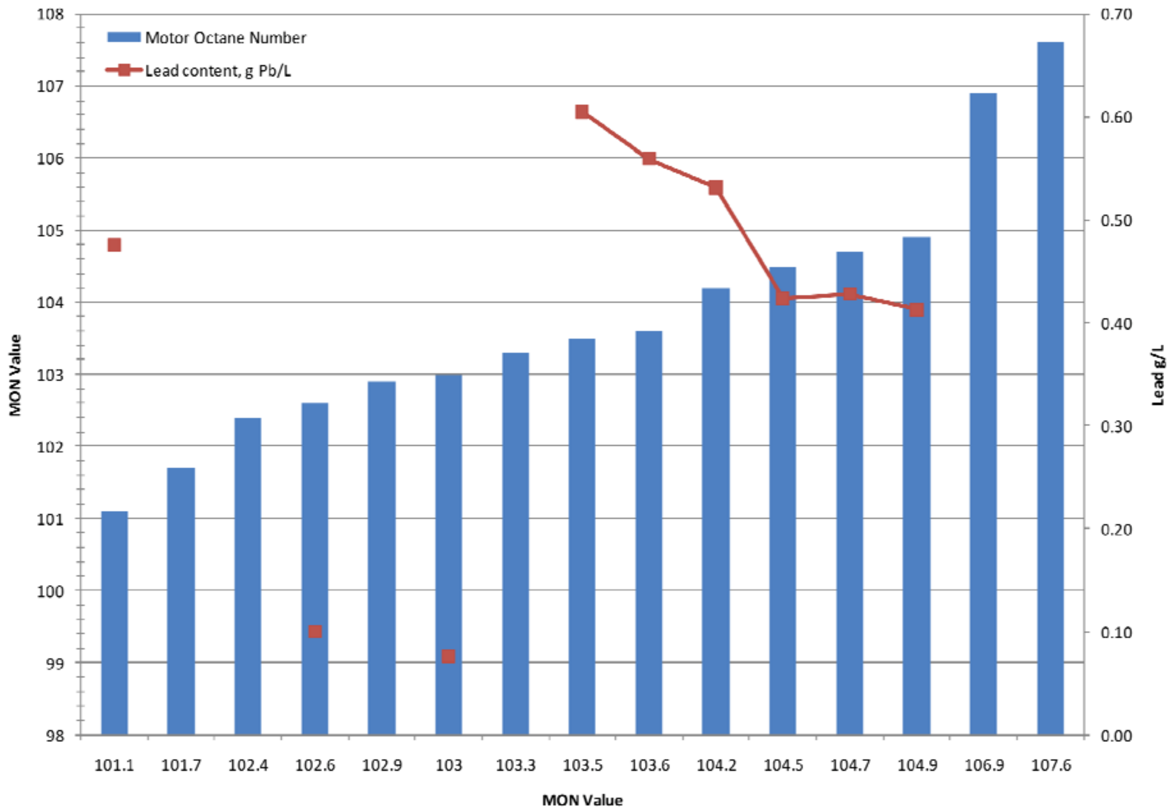

Figure 8. The MON vs Lead Content Specific to the Engine-Certified Fuels

The maximum lead content indicated for the engine certification fuels was 0.60 gPb/L, which is above the ASTM D 910 specification maximum allowance. The minimum lead content indicated was 0.08 gPb/L. This 0.08 value may have been a typographical error, as it was reported to be 0.29 gPb/gal, which would have been more in line with other data as 0.29 gPb/L. As entered, the median lead content was 0.43 gPb/L and the mean was 0.40 gPb/L, which was slightly lower than the mean for all the data samples.

This data set, like the CoAs data set, indicated approximately 40% of the samples were able to meet the 20% reduction in maximum lead content; 67% of the samples met the 15% reduction in maximum lead content; and 67% of the samples met the 10% reduction in maximum lead content.

CONCLUSIONS

The general aviation gasoline user community has established a goal to reduce the amount of lead added to current aviation gasoline. The research evaluated lead additive levels in commercially available aviation gasolines currently meet the ASTM D 910 specification for 100 low lead. Fuel samples, Certificates of Analysis (CoA), and fuel analyses from engine certification tests were obtained for contemporary loads of aviation fuels from a variety of fixed-base operators. The sample set included 83 individual data points that consisted of the collection of CoAs from fixed-base operators, CoAs from independent laboratories that were performed on a collection of airport fuel samples, engine manufacturer's records for fuels that were used for certifications, and from data collected by the ASTM National Exchange Group (NEG). Based on the review of the provided data, basic conclusions can be drawn.

- For the sample data, 43% of the samples currently produced are below the maximum lead content at a 20% reduction over current specification lead levels. At a 15% reduction from the current maximum allowable lead content, approximately 55% of the samples would meet specification. At a 10% reduction, approximately 67% would meet specification.

- For an agglomeration of the sample data, the mean elemental lead content was 0.46 gPb/L and the median was 0.48 gPb/L. The maximum was 0.60 gPb/L, and the minimum was 0.08 gPb/L.

- Of the nine engine certification fuels with indicated lead content, 44% could meet the 20% reduction and 67% could meet the 15% reduction, which is in agreement with the fielded data. The mean motor octane number (MON) value was 103.6. The maximum MON value was 108, and the minimum MON value was 100.

- Of the 15 total engine certification fuel samples, the mean MON value was 103.8. The maximum MON value was 107.6, and the minimum MON value was 101.1.

- One of the primary suppliers of fuel, which represented 23% of the data set, could not meet a 20% reduction of the maximum lead level. This supplier met the maximum lead level at a 15% reduction in 11% of the samples.

- There does not appear to be a relationship between regions and lead content, excluding the impact of the single refinery on the region data.

- No obvious relationship can be drawn based on the lead and aromatics content data due to the lack of aromatic content data and no information on alkylate quality. There were instances of high lead with high aromatics and low lead with high aromatics.

- Similarly, no relationship was found between the lead level and the MON or the supercharge rating.

- Of the total samples reviewed, over 95% had MON values higher than 102, and 85% had MON values over 103.

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1. ASTM D 910, "Standard Specification for Aviation Gasolines," American Society for Testing and Materials, West Conshohocken, Pennsylvania, 2007.

2. ASTM D 2700-09, "Standard Test Method for Motor Octane Number of Spark-Ignition Engine Fuel," American Society for Testing and Materials, West Conshohocken, Pennsylvania, 2009.