Leaded Fuels are More Common than You Think

By Garrett Heffern

Lead's toxic nature has been documented for centuries. Extreme exposures can damage the brain and kidneys for adults; however, children are especially susceptible to lead poisoning.[1] Prolonged exposure to even low levels of lead can cause anemia, behavioral and learning disorders, and nervous system damage in children.[2] Yet, while the United States banned leaded paints in 1978 and the sale of leaded automobile fuels in 1991, the airplane industry still releases tons of lead compounds into the atmosphere each year. General Aviation (GA) is responsible for 70% of the lead which enters the environment annually.[3] If a single industry contributes so much to lead poisoning, why do lawmakers let it continue? The reason lies with leaded fuels.

Despite the known health risks of lead exposure, the 20th century found a new demand for the element: automobiles. During the car boom in America, automotive manufacturers realized that the speed of their cars was limited by the power of their engines. The predominant engine, the internal combustion engine, injects a gaseous fuel and air mixture into a cylinder, compresses that fuel-air mixture using a piston, and ignites the mixture with a spark plug. The mixture combusts, expands, and exerts work on the piston, driving the engine. To exert maximum work and produce maximum power, the engines must compress the fuel-air mixture in each cylinder as much as possible. However, the low octane gasolines of the time would combust prematurely under higher compression pressures before reaching the spark plug. This detonation,

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[1] Lead. (2021, December 8). Centers for Disease Control and Prevention. Retrieved November 6, 2022, from https://www.cdc.gov/niosh/topics/lead/health.html

[2] Stolark, J. (2016, March 30). Fact Sheet | A Brief History of Octane in Gasoline: From Lead to Ethanol. Environmental and Energy Study Institute. Retrieved November 6, 2022, from https://www.eesi.org/papers/view/fact-sheet-a-brief-history-of-octane

[3] Sale of Leaded Aviation Fuel Ends at Reid-Hillview and San Martin Airports. (n.d.). County of Santa Clara Office of Communications and Public Affairs. Retrieved November 6, 2022, from https://news.sccgov.org/newsroom/reid-hillview-airport-airborne-lead-study

called knock, reduced engine power and damaged the pistons, often leading to engine failures. Automobile companies raced for a more compressible fuel.

Thus, in 1921, tetraethyl lead (TEL) was introduced.[4] Just 0.8 mL of TEL fluid dissolved in each liter of gasoline increased the fuel's octane rating from 40-60 to around 100 octane.[5] Marketed merely as Ethyl Gasoline, TEL soon became the primary octane enhancer for cars, ships, motorcycles, and airplanes. TEL was especially favored in aircraft engines which, unlike car engines, must be capable of cruising at 75% of their peak power for hours on end.[6] But what does TEL really do?

The name "octane" refers to a specific type of hydrocarbon chain. The term hydrocarbon, refers to any molecule composed of hydrogen and carbon. However, these molecules have a unique structure consisting of a chain of carbon atoms each bonded with hydrogen atoms or other hydrocarbon molecules. When hydrocarbons are heated in the presence of an oxidizer like oxygen, they combust to form carbon dioxide (CO_2) and water (H_2O). Some examples of these molecules are methane, with one carbon atom, propane with three carbon atoms in a chain, and butane, with four carbon atoms in a chain. Octane just refers to a chain of eight carbon atoms. As shorter chains of carbon atoms tend to combust under lower compression, engineers sought to add longer hydrocarbons, octanes, to gasoline.[7]

TEL has a chemical formula of $(CH_3CH_2)_4Pb$, and a structure of eight carbon atoms around a central lead atom. These hydrocarbons allowed the air-fuel mixture injected into the

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[4] Beychok, M., Berkowitz, H. C., & Argyriou, A. (2012, February 22). Tetraethyl lead. Citizendium. Retrieved November 6, 2022, from https://en.citizendium.org/wiki/Tetraethyl_lead

[5] Beychok, M., Berkowitz, H. C., & Argyriou, A. (2012, February 22). Tetraethyl lead. Citizendium. Retrieved November 6, 2022, from https://en.citizendium.org/wiki/Tetraethyl_lead

[6] Pope, S. (2012, April 10). Do Car Engines Make Good Airplane Engines? Flying. Retrieved November 6, 2022, from https://www.flyingmag.com/aircraft-do-car-engines-make-good-airplane-engines/

[7] Brain, M. (n.d.). What Does Octane Mean? howstuffworks. Retrieved November 6, 2022, from https://auto.howstuffworks.com/fuel-efficiency/fuel-consumption/ question90.htm

cylinder to compress greater amounts without detonating. However, once the gasoline combusted, the lead reacted with the oxygen to form lead-oxide (PbO). This lead-oxide often did not completely exhaust and built up within engines, causing wear and damage. Thus the TEL fluid used in aircraft fuels today consists of 61.45% TEL, 1.90% dye or inserts, 17.85% 1,2-Dibromoethane, and 18.80% 1,2-Dichloroethane. The latter two substances react with the lead after combustion to form lead bromide ($PbBr_2$) and lead chloride ($PbCl_2$). These compounds are exhausted into the atmosphere with minimal buildup in the engine.[8]

Though beneficial for engines and airplanes, the lead compounds can have grave consequences on the ground. The common 100 octane low-lead (100LL) aviation gasoline, has a maximum lead content of 0.56 grams per liter.[9] Though this might seem insignificant, about 170,000 aircraft in the US burn this fuel each year[10] while the most common (most produced) airplane has a fuel burn of around 26.5 L to 34 L per hour.[11] Despite the lead content in 100LL being as low as possible, the scale of General Aviation makes the lead emissions unacceptable. Though ethanol has been the leading replacement for TEL in cars,[12] it can only efficiently deliver the octanes of 87, 89, or 91 which you see at the gas station.[13] Though seemingly a marginal

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[8] Beychok, M., Berkowitz, H. C., & Argyriou, A. (2012, February 22). Tetraethyl lead. Citizendium. Retrieved November 6, 2022, from https://en.citizendium.org/wiki/Tetraethyl_lead

[9] Stumpf, R. (2021, September 2). If Leaded Fuel Is so Bad, Why Are Airplanes Still Using It? The Drive. Retrieved November 6, 2022, from https://www.thedrive.com/news/42218/if-leaded-fuel-is-so-bad-why-are-airplanes-still-using-it

[10] Stumpf, R. (2021, September 2). If Leaded Fuel Is so Bad, Why Are Airplanes Still Using It? The Drive. Retrieved November 6, 2022, from https://www.thedrive.com/news/42218/if-leaded-fuel-is-so-bad-why-are-airplanes-still-using-it

[11] Cessna 172 Operating Cost. (n.d.). BWIFLY. Retrieved November 6, 2022, from https://bwifly.com/cessna-172-operating-cost/

[12] Stolark, J. (2016, March 30). Fact Sheet | A Brief History of Octane in Gasoline: From Lead to Ethanol. Environmental and Energy Study Institute. Retrieved November 6, 2022, from https://www.eesi.org/papers/view/fact-sheet-a-brief-history-of-octane

[13] Lippman, D. (2022, June 28). VERIFY: Is there more ethanol in our gasoline? CBS19. Retrieved November 6, 2022, from https://www.cbs19.tv/article/news/verify/is-there-more-ethanol-in-our-gasoline/501-696917cc-40b9-4aa2-8078-f690fe3fb48b

increase, the 100 octane level of Aviation Gasoline is vital for airplanes flying at high altitudes and at high percentages of their maximum power.[14]

However, not all hope is lost. Some GA airports currently offer UL94 (unleaded 94 octane fuel). But more importantly, a G100UL fuel (100 octane unleaded fuel) has just been developed.[15] The FAA recently approved G100UL's use for all piston powered, spark plug aircraft—a huge step toward the transition to unleaded fuels.[16] In detonation testing, G100UL matched or exceeded the performance of 100LL.[17] Both the 100 octane fuels can also be mixed and still power the engine.[18] The composition of G100UL has not yet been publicly released and it is expected to have a higher price than 100LL.[19] Though G100UL won't completely replace 100LL anytime soon, an alternative fuel has been certified, promising a significant reduction of lead in our environment in future years.

[14] Stumpf, R. (2021, September 2). If Leaded Fuel Is so Bad, Why Are Airplanes Still Using It? The Drive. Retrieved November 6, 2022, from https://www.thedrive.com/news/42218/if-leaded-fuel-is-so-bad-why-are-airplanes-still-using-it
[15] G100UL™ Avgas in the news. (2022, September 1). General Aviation Modifications, Inc. Retrieved November 6, 2022, from https://gami.com/g100ul/news.php
[16] G100UL™ Avgas in the news. (2022, September 1). General Aviation Modifications, Inc. Retrieved November 6, 2022, from https://gami.com/g100ul/news.php
[17] Unleaded Avgas. (2022, September). AVFuel. Retrieved November 6, 2022, from https://www.avfuel.com/Fuel/Alternative-Fuels/Unleaded-Avgas
[18] Unleaded Avgas. (2022, September). AVFuel. Retrieved November 6, 2022, from https://www.avfuel.com/Fuel/Alternative-Fuels/Unleaded-Avgas
[19] Unleaded Avgas. (2022, September). AVFuel. Retrieved November 6, 2022, from https://www.avfuel.com/Fuel/Alternative-Fuels/Unleaded-Avgas

References

Beychok, M., Berkowitz, H. C., & Argyriou, A. (2012, February 22). *Tetraethyl lead*. Citizendium. Retrieved November 6, 2022, from https://en.citizendium.org/wiki/Tetraethyl_lead

Brain, M. (n.d.). *What Does Octane Mean?* howstuffworks. Retrieved November 6, 2022, from https://auto.howstuffworks.com/fuel-efficiency/fuel-consumption/question90.htm

Cessna 172 Operating Cost. (n.d.). BWIFLY. Retrieved November 6, 2022, from https://bwifly.com/cessna-172-operating-cost/

G100UL™ Avgas in the news. (2022, September 1). General Aviation Modifications, Inc. Retrieved November 6, 2022, from https://gami.com/g100ul/news.php

Lead. (2021, December 8). Centers for Disease Control and Prevention. Retrieved November 6, 2022, from https://www.cdc.gov/niosh/topics/lead/health.html

Lippman, D. (2022, June 28). *VERIFY: Is there more ethanol in our gasoline?* CBS19. Retrieved November 6, 2022, from https://www.cbs19.tv/article/news/verify/is-there-more-ethanol-in-our-gasoline/501-696917cc-40b9-4aa2-8078-f690fe3fb48b

Pope, S. (2012, April 10). *Do Car Engines Make Good Airplane Engines?* Flying. Retrieved November 6, 2022, from https://www.flyingmag.com/aircraft-do-car-engines-make-good-airplane-engines/

Sale of Leaded Aviation Fuel Ends at Reid-Hillview and San Martin Airports. (n.d.). County of Santa Clara Office of Communications and Public Affairs. Retrieved November 6, 2022, from https://news.sccgov.org/newsroom/reid-hillview-airport-airborne-lead-study

Stolark, J. (2016, March 30). *Fact Sheet | A Brief History of Octane in Gasoline: From Lead to Ethanol*. Environmental and Energy Study Institute. Retrieved November 6, 2022, from https://www.eesi.org/papers/view/fact-sheet-a-brief-history-of-octane

Stumpf, R. (2021, September 2). *If Leaded Fuel Is so Bad, Why Are Airplanes Still Using It?* The Drive. Retrieved November 6, 2022, from https://www.thedrive.com/news/42218/if-leaded-fuel-is-so-bad-why-are-airplanes-still-using-it

Unleaded Avgas. (2022, September). AVFuel. Retrieved November 6, 2022, from https://www.avfuel.com/Fuel/Alternative-Fuels/Unleaded-Avgas