General Aviation Modifications, Inc.

2800 Airport Rd.
Ada, OK 74820

G100UL and xG100UL DETONATION TEST RESULTS

Report 06-6570040 Revision: Initial Release (IR) March 7, 2021

	Name	Signature	Date
Author:	J. Nell/G. Braly	(On file)	03-07-2021
Checked:	T. Roehl	(On file)	03-07-2021
Approved:	G. Braly DERT-830960-SW	(On file)	03-07-2021

FAA Project Numbers: ST06669WI-E (was ST13515AT-E) and ST06671WI-E.

ABSTRACT
14 CFR §33.47 Detonation test

This report details the results of the successful detonation testing of unleaded high octane G100UL and xG100UL fuel chemistries when operated on a high compression, turbonormalized engine. The engine configuration was purposefully selected to enable the unleaded fuel chemistries to be simultaneously tested on both a high compression and a turbocharged engine in one test. In addition, the manifold pressure and horsepower were purposefully increased so that the BMEP of the test engine would exceed that of any other high compression engine and be comparable to all turbocharged engines now in operation in the general aviation fleet.

The two unleaded fuel chemistries are included in the scope of the referenced pending project numbers for inclusion in one or more AML STCs to allow the use of these unleaded aviation gasolines as a functional drop-in replacement for ASTM D910 100 Low Lead aviation gasoline. As the central aspect of the testing described in this report, these two fuel chemistries were directly compared to a conforming D910 100LL for their detonation characteristics.

There were more than two dozen back-to-back engine mixture sweep comparisons between D910 100LL and the GxG100UL fuel chemistries. In every instance, and at every combination of manifold pressure, RPM, & fuel flow, the unleaded fuel chemistries were observed to be an improvement compared to the D910 100LL.

The detonation testing was conducted at the GAMI Engine Test Facility, in conformity with an FAA approved Detonation Test Plan. The FAA observed the testing in Ada, Oklahoma on December 15 & 16, 2020.

Note: G100UL™ and xG100UL™ are trademarks of General Aviation Modifications, Inc.

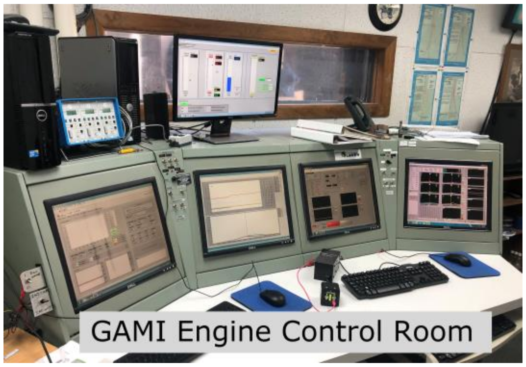
Appendix A - Executive Summary

On December 15 & 16, 2020, GAMI successfully completed the FAA engine test stand detonation related certification testing required for the approval of the G100UL™ & xG100UL™ fuel chemistries for use in aircraft spark ignition piston engines. These unleaded fuel chemistries have been under development by GAMI for the past 11 years. The cognizant FAA project engineer was onsite at GAMI's Aircraft Engine Test Facility to observe all of the testing.

Two different versions (each) of G100UL and xG100UL were tested, along with multiple "mixed" blends of each of these fuel chemistries and various fractions of conforming ASTM D910 100LL. The formulations of each of these two fuel chemistries comprised both a minimum octane value (conforming to the test specification) and a second formulation, more representative of fuel as it will be delivered in the general aviation airport environment.

A representative sample of conforming 100LL with a MON exceeding the lower end of the MON value specified in the ASTM D910 specification was used as a "reference" fuel for comparison during back-to-back testing with the unleaded fuel chemistries.

A 310+ BHp high compression (8.5:1) six-cylinder, horizontally opposed engine, equipped with turbochargers and electronic wastegate controls was used as the test engine, in order to generate (with increased MAP) the elevated engine BMEP values necessary in order for the results to be representative of, and, in fact, exceed the detonation resistance requirements of all of the engines in the existing fleet of general aviation spark ignition piston powered aircraft. During the detonation testing, the engine was routinely operated at 330-340 BHp and, in one series of tests, at 380 BHp. Each of these tests included operation at (or in excess of) OEM limiting engine operating parameters (MAP, CHT, IAT, Oil T, etc) required for original engine certification pursuant to 14 CFR Part 33. Each test included appropriate "sweeps" of the F/A ratio to explore the most detonation critical portions of the engine operating envelope.


GAMI Engine Control Room

The GAMI engine test stand is comprehensively equipped with state of the art detonation measurement hardware and software. The detonation test methods, hardware, software, computational algorithms, and quantitative "Pass/Fail" requirements were previously FAA approved by a formal, 14 month long FAA "Issue Paper" process. (Ref. 3) All test equipment and sensors were conformed and calibrated prior to the initiation of the testing.


GAMI Aircraft Engine Test Facility

Uniformly, the detonation intensities observed during testing for even the minimum-octane versions of the candidate unleaded aviation fuels demonstrated noticeably improved (lower) detonation levels than the reference formulation of the ASTM D910 conforming 100LL. The measured detonation intensities for the more representative "commercial" versions of the candidate unleaded aviation fuels were typically only a fraction of those more-intense levels of detonation observed for the reference 100LL.

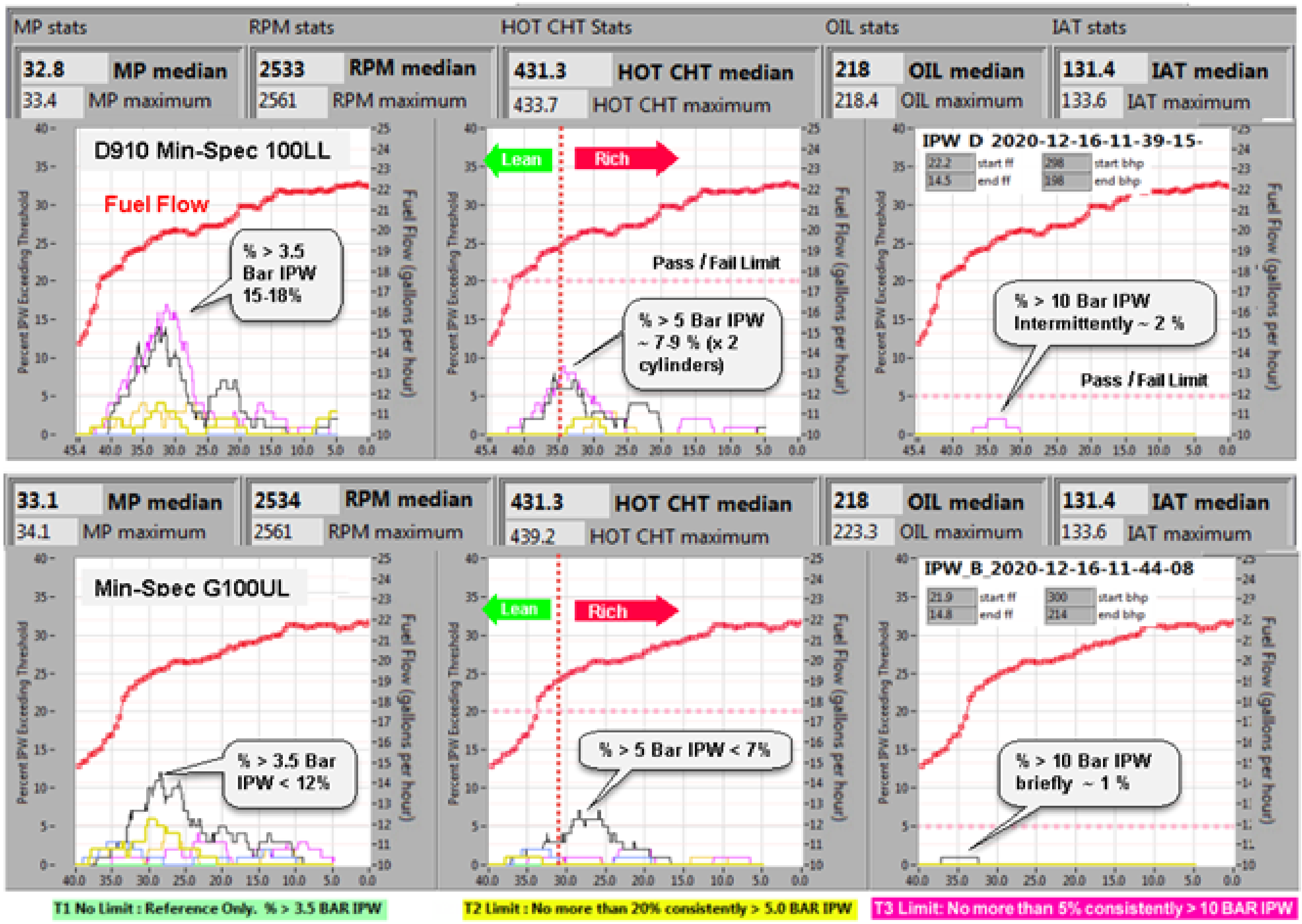
In mid-January of 2021, as this report was being drafted, The National Academy of Sciences issued its draft report "Options for Reducing Lead Emissions from Piston-Engine Aircraft" (Ref 12 & Appendix "I"), and stated:

> "A key message of this report is that a lead mitigation strategy focused almost entirely on developing an unleaded drop-in fuel that would eliminate aviation lead emissions has a high degree of uncertainty of success given the formidable technical challenges."

The successful completion of the detonation testing described in this report, along with the earlier successful completion of aircraft/engine material compatibility testing, in-flight operability, climb cooling, and related hot weather testing (References 4, 5, 6, 7, 8 & 9) demonstrate that, contrary to the recent statements by the National Academy of Sciences, the "technical challenges" ***have been*** successfully overcome and a "functional drop-in" replacement fuel for leaded aviation gasoline ***has been*** identified and extensively and successfully tested by the traditional FAA Certification methodology.

GAMI would like to specifically acknowledge some of the key people in the FAA certification field who have been central to the successful results described in this report. These individuals include (early in the project) Fran Favera (retired, former head of the Engine Propeller Directorate); Jurgen Priester from the Fort Worth Aircraft Certification Office (ACO); and, Kevin Brane (retired) from the Atlanta FAA ACO. Moreover, at critical junctures in this project, Senior FAA management has intervened to untangle Administrative "bottlenecks". Among these key persons are Dorenda Baker (AIR-1) who intervened on three specific occasions, to decisively resolve administrative complexities and place alternative FAA personnel resources in charge of this project. More recently, Ms. Baker's successor as AIR-1, Earl Lawrence, has also intervened in order to reorganize and greatly simplify the administrative management of this project. Without those timely interventions, this project would not, now, be on the threshold of successfully solving the most visible threat facing the general aviation piston engine community.

Direct Comparison of Detonation Characteristics of
"Min-Spec" (Octane) 100LL (top row) to "Min-Spec" G100UL (bottom row)



The vertical axis on the left side of each graph is the percentage of individual combustion events - - out of the most recent 100 combustion events for each cylinder - - that exceed the defined T1, T2, T3 thresholds for detonation intensity. The values are color coded by individual cylinder. Detonation intensity, (in units of pressure - BAR) is calculated using methods and algorithms approved by the 2015 FAA Issue Paper.

The vertical axis on the right side of each graph is the fuel flow during a mixture "sweep" (right to left) at the referenced operating conditions. The X-axis is time, in seconds, during the mixture sweep.

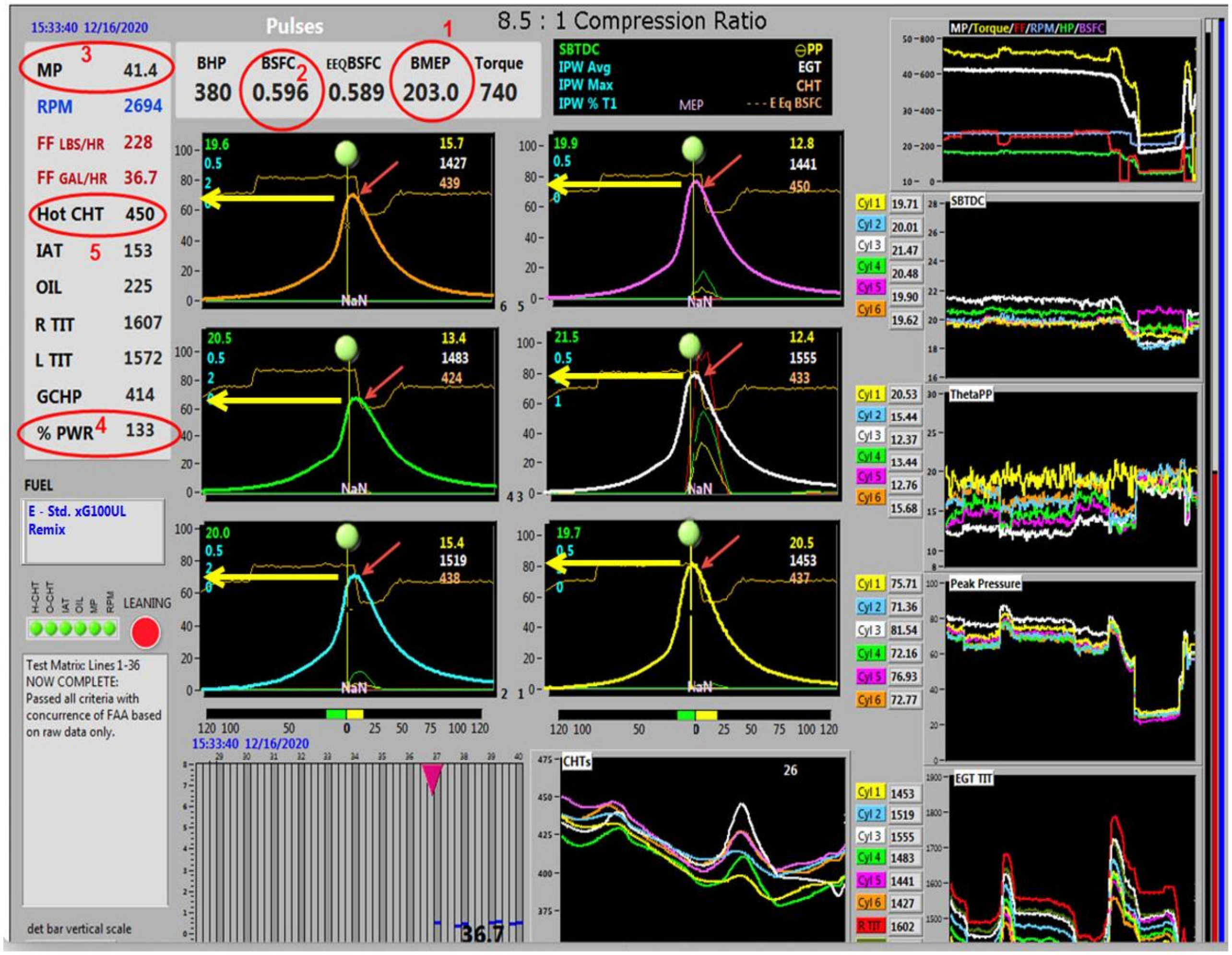
The instrumentation, software, test stand, and fuel chemistries were previously calibrated and conformed by the FAA. Pursuant to an exception to Covid restrictions, the FAA was present, in person, in Ada, Oklahoma, December 15 & 16th, 2020 to observe the testing.

The range of fuel/air ratios covered by these mixture sweeps includes the area of operation known to be most likely to result in detonation. These mixture sweeps were repeated with consistent results.

In order to assure sufficient detonation to allow a comparison of 100LL to the candidate UL fuel chemistries, and with the agreement of the FAA, the severity of the operating conditions were increased so those conditions substantially exceeded the OEM intended area of operations (Example: 33" MAP vs 29.6") and the CHTs are in excess of the OEM recommended CHTs for continuous engine operation. The Induction Air Temperatures (IATs) are consistent with an ISA + 60 deg. F day. The operating conditions are virtually identical for both sets of data.

The conforming minimum octane specification unleaded fuel chemistry is rather clearly an improvement over the minimum octane specification ASTM D910 100LL.

Figure 2. Annotated comparison of detonation characteristics of D910 100LL and a minimum octane formulation of the G100UL unleaded fuel chemistry at "Condition B1", from Table 5.



(1) BMEP = 203 PSI; (2) The BSFC was 0.596 lb/hr/hp, which is approximately 15-18% leaner than a normal full rich mixture and, therefore, conforms to the lean-down requirements for full power detonation testing set forth in 14 CFR 33.47; (3) The Manifold Pressure (41.4" Hg.) was ~11.4" more than the OEM limit for this engine; (4) The 380 BHP, corrected to ISA Std. Conditions **(~414 BHP)** was ~ **133% of the OEM certified horsepower** (310 BHP); (5) The hottest CHT was 450° F (Redline = 460° F). A review of the six engine combustion pressure traces reveals that there was zero evidence of any detonation, nor even any combustion instability, much less any higher levels of detonation that would have still been deemed to be acceptable for certification (see the six red arrows in the image). The peak internal cylinder combustion pressures are at levels of 70 to 80 BAR (see yellow arrows), which is 20-25% higher than the peak internal cylinder pressures that would be observed during normal operation of this engine at its OEM/FAA approved maximum BHP.

Figure 7. Data demonstrating operation of a high compression turbocharged engine at extremely high power settings at limiting certification conditions. This data point **(Condition A3)** was optional, to be addressed at the conclusion of the testing. This data is consistent with the ASTM D909 laboratory data for the GxG100UL fuel chemistries which typically returns values for "Performance Numbers" substantially greater than the historic "purple gas" used in the piston airliners with a MON/PN number of 115/145. The measured "Performance Number" (aka the "Rich Rating") of the GxG100UL fuel chemistries has never been measured less than 150, and is normally so high that the existing D909 laboratory report sometimes simply states the value as "in excess of 160"**.**