RACING MERLINS

From Cleveland to Reno Part II

by Birch J. Matthews and Dustin W. Carter

Volume 33, Number 2 of the Journal *presented an excerpt from the forthcoming book,* Mustang—The Racing Thoroughbred. *The historical evolution of* Merlin *engines was recounted together with a recitation of modifications to achieve the quintessential air racing powerplant; in other words, the most perfect embodiment of a racing engine. This segment is a companion to the Volume 33 article in that racing fuels and additives are discussed both from a historical aspect as well as current day practice.*

Depending upon one's perspective, aircraft piston engine development may be viewed from strides made in metallurgy, supercharging, cooling technology, lubrication and engine design configuration. Absolutely critical and perhaps most important to aircraft engine progression was the evolution of high-performance aviation fuels. Without such fuels, even the finest metallurgical advances would not have sufficed. Supercharging would have been of marginal use. Fuel research and development, however, allowed engine designers to conquer the beast of detonation or "knock" and achieve rather astounding power outputs from *Merlins* and other well-known engines.

The late C.F. Kettering of General Motors stated the relationship between fuels and internal combustion engines when he said, "We fully realized that it was the combination of engines and fuels and not either one of them alone that develops useful power." This is certainly true with respect to racing engines. Maximum useful power from a *Merlin* engine is very dependent upon the quality of fuel employed. Historically, high-performance racing fuels include both gasoline blends and various alcohol-based combinations. Gasolines are produced by distilling or "cracking" crude oils while alcohols are synthesized from various hydrocarbons such as coal, natural gas and petroleum products.

Alcohol Fuels—Prior to development of truly high-octane aviation gasolines during the 1930s, alchohol blends were frequently used in high-performance racing engines. There were at least two factors influencing this trend. During World War I and into the 1920s, available gasolines were not only noisome but of perhaps no more than 50-octane rating. As such, they were highly susceptible to detonation or as it was commonly called, knock. And secondly, especially in Europe, alcohol production was typically a government-controlled monopoly. Excess alcohol was directed into various fuel markets, a process somewhat dependent upon how much it took to slake their citizens' thirst. Thus in early years, the quality of alcohol-gasoline blends varied with supply and various demands such as heating, lighting and motoring fuels. Racing participants increasingly resorted to precisely mixed alcohol-based fuels to facilitate high-compression ratio or supercharged engine operation without detonation.

Although of lesser chemical energy than gasolines, alcohol fuels provide knock or detonation resistance when used in supercharged engines. The British, for instance, used an alcohol-based fuel in their 1931 Schneider Trophy-winning *Supermarine* S.6B racer. The S.6B powerplant was a Rolls-Royce 2,240-cubic-inch "R" engine supercharged to deliver over 2,300 horsepower when operated on a blend of 60 percent methyl alcohol (methanol), 10 percent acetone and 30 percent benzol. Now, benzol is a colloquial term applied to mixtures of benzene and toluol.* A mixture commonly used in the United States for motor racing during the 1930s was benzol 90s. This nomenclature indicated that its volatility was high: 90 percent of the mixture boiled upon reaching 212 degrees Fahrenheit.

Although alcohol blends and alcohol-gasoline combinations provide detonation resistance for supercharged engines, their limitation is lower energy content per pound relative to high-grade gasolines. The chemical energy content of a fuel is defined as its heating value and measured in terms of British thermal units (BTUs) per pound. This is the amount of heat required to raise one pound of water one degree Fahrenheit in temperature. The inherent disadvantage of using alcohol-based fuels in high-performance racing engines is seen in the accompanying list of some common fuels including aviation gasoline.

*Benzene and toluol (a commercial form of toluene) are both hydrocarbons possessing good anti-knock qualities for supercharged engines.

Although relatively stock in outward appearance, Wiley Sanders' *Mustang* has all of the current technology under the cowling including ADI and spray bars. The result is a serious *Merlin*-powered machine.
(Birch Matthews)

PROPERTIES OF COMMON FUELS

Fuel	Heating Value Btu/Lb	Weight Lb/Gal	Heat of Evaporation Btu/Lb	Octane Rating	Remarks
Aviation Gasoline (115/145)	18,800	6.0	130	115/145	Performance Number
Xylene (91% Pure)	17,800	7.2	145	Unknown	
Toluene	17,500	7.2	150	98	
Benzene	17,300	7.3	170	88–110	
Acetone	12,300	6.6	170	100	Used as a mixing agent
Ethyl Alcohol	11,600	6.6	390	99	
Methyl Alcohol	8,600	6.6	470	90–100	
Rolls-Royce Mixture No. 1	17,600	7.0	160	96	3.3 cc tetraethyl lead
Rolls-Royce Mixture No. 2	16,700	7.0	192	95	3.3 cc tetraethyl lead
Rolls-Royce Mixture No. 3	11,600	6.8	350	92	4.1 cc tetraethyl lead
Methyl Alcohol/Nitromethane	7,800	7.2	425	Unknown	80%–20% blend
Benzol 90s	17,500	7.3	162	95–100	60% benzene, 40% toluol

Notes

1. Rolls-Royce Mixture No. 1 consisted of 78% benzol and 22% gasoline from Romanian fields. This blend was used during the 1929 Schneider Cup Race in the Rolls R engine.
2. Rolls-Royce Mixture No. 2 consisted of 70% benzol, 10% methyl alcohol and 20% gasoline from California fields. This blend was used during the 1931 Schneider Cup Race in the R engine.
3. Rolls-Royce Mixture No. 3 consisted of 30% benzol, 60% methyl alcohol and 10% acetone. This blend was used in the R engine during the successful run for the world absolute speed record in 1931.
4. Chuck Brown and Don Noland of Allison Engineering Division ran what was essentially Rolls Mixture No. 3 in a Bell P-39Q powered by a highly modified Allison V-1710 G series engine. These tests were conducted in 1948 prior to the National Air Races.
5. John Sandberg ran methyl alcohol in a Bell P-63C powered by another highly modified Allison V-1710 engine at the Reno National Championship Air Races in 1974.

Heating values given in this table show, for instance, that a racing airplane using a supercharged engine would have to carry more than twice as much methyl alcohol as aviation gasoline to achieve the same power setting during a race of fixed distance. This disadvantage is compounded due to the fact that methyl alcohol is 10 percent heavier than gasoline. Even though fuel is burned off during the course of a race, the initial fuel weight penalty and volume requirement at takeoff is quite significant for most alcohols.

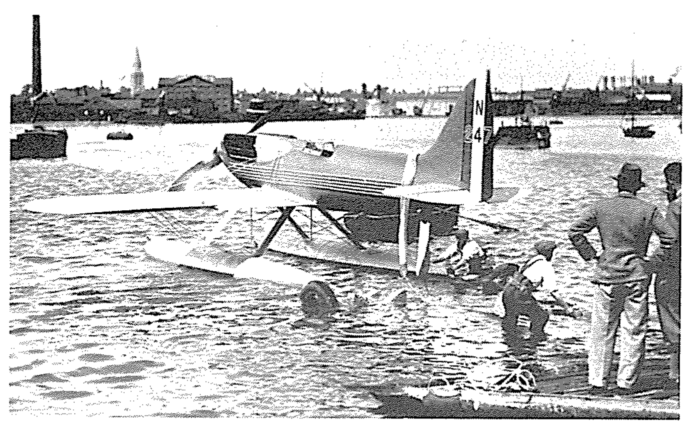
A comparison of methyl alcohol with aviation gasoline is perhaps an extreme case. In reality, supercharged engine performance may be obtained by blending various alcohols both with and without gasolines. The objective is to achieve detonation resistance while still maintaining some reasonable energy content and other important fuel characteristics. This is why benzol with its relatively high heating value was usually a fuel constituent in many racing engines before World War II.

For their successful record run of 1931, Rolls-Royce engineers utilized a blend of methyl alcohol, benzol and acetone upon the advice of F.R. (Rod) Banks. This fuel cocktail, combined with the R engine and Supermarine S.6B airframe produced an absolute speed record of 407 miles per hour; a phenomenal velocity achieved less than three decades following man's first tenuous powered flight. It is interesting to note that the 1931 fuel blend resulted in a heating value of about 11,600 BTUs per pound of fuel. Had high-octane aviation gasoline of World War II been available in 1931, the Supermarine S.6B fuel load would have been reduced some 40 percent.*

*Octane rating of fuels is based upon comparative testing with mixtures of normal heptane which detonates easily and iso-octane which is quite resistant to detonation. These two fuels have arbitrary octane ratings of 0 and 100, respectively. To determine an octane number, tests are conducted in a special unsupercharged engine at standard conditions using a relatively lean fuel-air mixture ratio. Test engine compression is increased until the onset of detonation is reached. Thus through comparative testing, a gasoline exhibiting a tendency to detonate at the same point as a mixture of 80 percent iso-octane and 20 percent heptane would be rated at 80 octane.

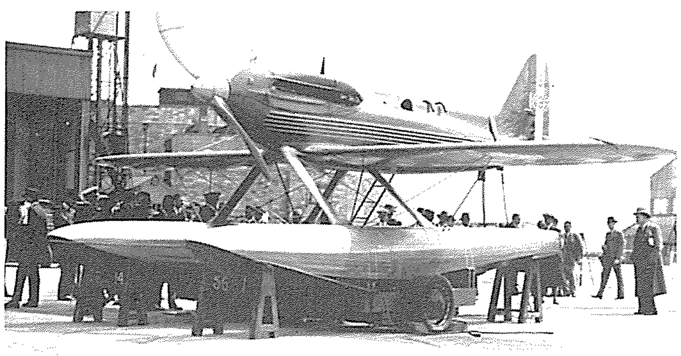
Alcohol-based fuels have enjoyed sporadic usage among post-World War II and contemporary unlimited class air racers. In addition to weight and tank volume penalties, alcohols chemically attack materials commonly used for fuel system seals and tank bladders. Lower alcohol blend heating values also require larger capacity fuel pumps to deliver an equivalent amount of energy to the engine. And to accept these higher flow rates, carburetor jets must be enlarged.

Four unlimited class air racers have experienced with alcohol-based fuels since World War II. The first was Chuck Brown's P-39Q-10 *Airacobra* entered in the 1948 National Air Races. This racer was powered by an Allison V-1710-G6 engine with the auxiliary stage supercharger removed and the engine stage supercharger regeared to an 8.8 to 1 ratio to increase fuel-air charge weight flow. The engine was prepared by Allison engineer Don Nolan to produce maximum race power. His preparation included consideration and testing of alcohol-based fuel blends. According to Nolan, "Flight tests were conducted with several fuels, principally methanol,



Supermarine S.6 N247 powered by the Rolls-Royce R engine fueled with a 78 percent benzol, 22 percent Romanian straight run gasoline. This combination won the 1929 Schneider Trophy Race at 329 mph.
(Vickers Armstrong)

Supermarine S.6B S1596 of 1931 set the world's absolute speed record of 407 mph. To develop more power, fuel was changed to 30 percent benzol, 60 percent methanol and 10 percent acetone which allowed greater supercharging. (Unknown)



Supermarine S.6B S1595 using an uprated Rolls-Royce R engine won the 1931 Schneider race. Rod Banks blended 70 percent benzol, 10 percent methanol and 20 percent California straight run gasoline. (Vickers Armstrong)

benzene and acetone mixtures. Complete recarburization was accomplished to match these requirements. Speed-power data were obtained which showed the aircraft to fly at speeds in excess of 438 mph true air speed on a measured mile (power set at 115 inches manifold pressure and 3,350 rpm). Comparative runs were also made using 2-4-4 tri-methyl butane (from Shell Oil) and water injection which showed reasonably good data as compared to the alcohol fuels with correspondingly less consumption. The decision was made to sacrifice the slight performance margin with the alcohol blends for a guarantee of sufficient quantity for the race.''

With the return of unlimited air racing at Reno in the 1960s, David Maytag entered a P-51D *Mustang*. During 1967, the *Merlin* engine setup was modified in a unique dual fuel configuration. Conventional aviation gasoline was used for startup, taxiing, takeoff and landing. High power race operation was to be conducted using methanol. This complex approach to an alcohol-fuel racer was the design product of Douglas Aircraft powerplant engineer, Al Heinike. In his own precise description, ''The methanol system was installed parallel with the existing gasoline system except that methanol was injected at the intake valves while the aviation gasoline was injected at the blower (supercharger) inlet in the normal manner.'' Maytag's race crew custom built the methanol injectors and calibrated them by flowing methanol through the injectors and catching the fluid in milk bottles. Maytag *Mustang* pilot Russ Schleeh stated that during flight he could ''pull 110 inches of manifold pressure using ADI (antidetonant injection fluid) with aviation gasoline but needed only 85 inches manifold pressure with methanol for about the same engine power levels.''

The Maytag *Mustang* methanol-fueled engine project had an unhappy ending. On the day before the Maytag crew was to leave for Reno and the races, Russ was flying a last test flight over California's Mojave desert. Applying power while running methanol, Russ's engine blew forcing him to make an emergency landing at Palmdale Airport. David Maytag lost interest in the project and it died aborning.

It was not until 1974 that race enthusiast, John Sandberg, gave alcohol fuels another shot. Armed with Don Noland's experimental data from 1948, John modified the Allison V-1710 engine in his Bell P-63C racer, *Miss Tipsie,* to run on methanol fuel. Methanol was port-injected using a Hillborne fuel injection system. Wet wings were used with a methanol-resistant sealant which provided a 565-gallon capacity, more than adequate for the Reno race course. Stainless steel was used throughout the fuel feed system. Even more adventuresome was incorporation of two Garrett turbochargers, one for each six-cylinder bank of the Allison. The engine was capable of up to 110 inches of manifold pressure, an impressive achievement. In spite of all his effort, John found the reconfigured Allison unreliable for racing and reverted to gasoline the next year.

The most recent attempt to employ alcohol-based fuels in an unlimited racer occurred during 1987. At Reno that year, Eric Lorentzen of Levelor-Lorentzen, Inc., entered a striking Hawker *Sea Fury* F.B. 11 incorporating a methanol-fueled Wright R3350-26WD radial engine. An electronic computer-controlled fuel injection system was utilized and the fuel feed system made compatible with methanol. In reality, fuel was a methanol-nitromethane blend and, based upon dynamometer tests, the Levelor people claimed power output in excess of 4,000 horsepower. This is an impressive 40 percent increase over a stock R3350. To feed this monster, fuel tank capacity was increased from 240 gallons to 301 gallons. Engine problems plagued this new racer and by race weekend, the methanol engine had been replaced by another R3350 burning conventional aviation gasoline.

Aviation Gasolines—Petroleum refinery engineers brought high-performance gasolines to reality during the 1930s, and development continued during World War II. These advancements allowed engine designers to routinely increase power by boosting manifold pressures to higher and higher magnitudes. The consequences of improved fuels were evident during World War II as numerous fighter aircraft including the *Mustang* were able to operate effectively at altitudes above 20,000 feet by using more supercharging.

The topic of gasolines is simultaneously broad and technically complex. Fuel research and development is the province of chemists although one suspects such research also contains a motivating dash of ancient alchemy, a Middle Ages philosophy principally concerned with turning baser metals into gold. How better to describe the transformation and monetary return from converting crude oil into high-performance aviation gasoline?

Aviation fuels consist primarily of four different series of hydrocarbons: namely, *aromatics, naphthenes, olefins* and *paraffins*. During the early years of aviation, gasolines were obtained by simple distillation of crude oils to obtain the lighter fractions—those hydrocarbons with boiling points of say 100 to 300 degrees Fahrenheit. These were so-called "straight run" gasolines and varied in quality from wretched (50 octane) to moderately acceptable (approaching 70 octane). Their consistency and quality, if you will, was dependent upon the oil fields from which they were derived. Thus, the racing technician of the late 1920s and early 1930s sought gasolines from fields rich in aromatics or naphthenes which possessed the highest and second highest anti-knock qualities, respectively. Aromatics, incidentally, had concentrations of benzene and toluene which by themselves were useful anti-knock ingredients in fuel blends during this era.

John Sandberg's beautiful red Bell P-63C-5 *Kingcobra* equipped with a dual Garrett turbocharger and setup to burn methanol fuel. Engine reliability problems plagued John and he reverted to aviation gasoline.
(Vlado Lenoch via Dick Phillips)

With this logic, it is understandable that Rod Banks selected California straight run gasolines as one fuel constituent for the 1931 Schneider Trophy Supermarine S.6B racer. California crudes were known to be high in aromatics. To deal with the high degree of supercharging employed in the R engine of the S.6B, Banks further improved his potion by adding large doses of methanol and benzol together with a lacing of tetraethyl lead. This chemistry yielded an octane rating of about 95 and a corresponding heating value of 17,500 BTU per pound. Earlier for the 1929 Schneider Race, Banks mixed benzol with Romanian gasoline, high in naphthenes, and fed it to the Rolls-Royce R engine powering the Supermarine S.6. Logistically, Romanian gasoline was in close proximity to Great Britain. Simultaneously, Rolls-Royce enjoyed a reasonable amount of time in which to prepare their racing engine. By contrast, precious little time existed for development and preparation of Britain's 1931 Schneider entrant, the S-6B. With attention to detail and seeking every advantage, Banks no doubt selected the marginally improved anti-knock quality of the distant California straight run gasoline. Britain's victory was the sum of all parts played in this international race project, not the least of which was the fuel blend.

With the passage of time, petroleum engineers and chemists became more sophisticated in cracking crude oils and in blending constituents to achieve consistent quality standards and octane ratings independent of the crude source. Thus it was that American air racers of the Depression '30s had access, if they could afford it, to 87-octane fuel which would allow moderate supercharging. One-hundred-octane aviation gasoline was in laboratory quantities by 1934. In a few short years, it was the Army Air Corps standard, and higher performance fuels were in the offing. These latter gasolines would be race tested at Cleveland following World War II.

Unlimited racers entered in the 1946 and 1947 National Air Races in Cleveland basically relied upon commercially available aviation gasoline having a performance number of 100/130.* Contemporary reports suggest that some of the entries modified their gasolines to a limited extent with addi-

*Aircraft engines frequently operate for periods of time at richer mixture ratios as during takeoff and climb. As more fuel is added, the charge cools and resistance to detonation typically increases. To account for this phenomenon, the performance number rating system for aviation gasolines was developed. Test engines used in grading fuels could vary mixture ratio as well as manifold pressure (supercharging). An aviation fuel performance number of 100/130 thus indicated that at lean mixture ratios the gasoline had an octane number of 100; however, at richer mixture ratios, the manifold pressure could be increased 30 percent with a corresponding power increase before detonation occurred. Similarly, the more recent 115/145 grade aviation fuel was approximately 15 percent more detonation resistant than the 100/130 performance number grade.

tives hopefully to further suppress detonation at race manifold pressures.

In 1948, however, Shell Oil Company introduced a limited quantity of what was billed as an outstanding new fuel called Methyl Triptane-1. The basis for triptane was actually not very new at all. This fuel was first formulated and reported in scientific literature during 1922 by Chavanne, a Belgian chemist.* It was subsequently made in laboratory quantities and first tested in an engine during 1926. By 1938, triptane had been tested in a supercharged engine and at this point, Wright Field engineers became interested in its possibilities. Research, development and limited production of triptane continued during World War II by General Motors Research Laboratories under sponsorship of the Army Air Forces. Results were impressive. Tests revealed that an Allison V-1710 engine with a rated takeoff power of 1,500 horsepower could deliver up to 2,500 horsepower using a mixture of 60 percent triptane and 40 percent 100-octane aviation gasoline. Introduction of triptane fuel by Shell for the 1948 races was perhaps an advertising coup d'etat over rival Standard Oil of Ohio, one of the race sponsors. Shell's triptane had a performance number of 200/300 and was practically free from any destructive detonation tendency. Without doubt it was the pinnacle in aviation gasoline development for reciprocating engines.

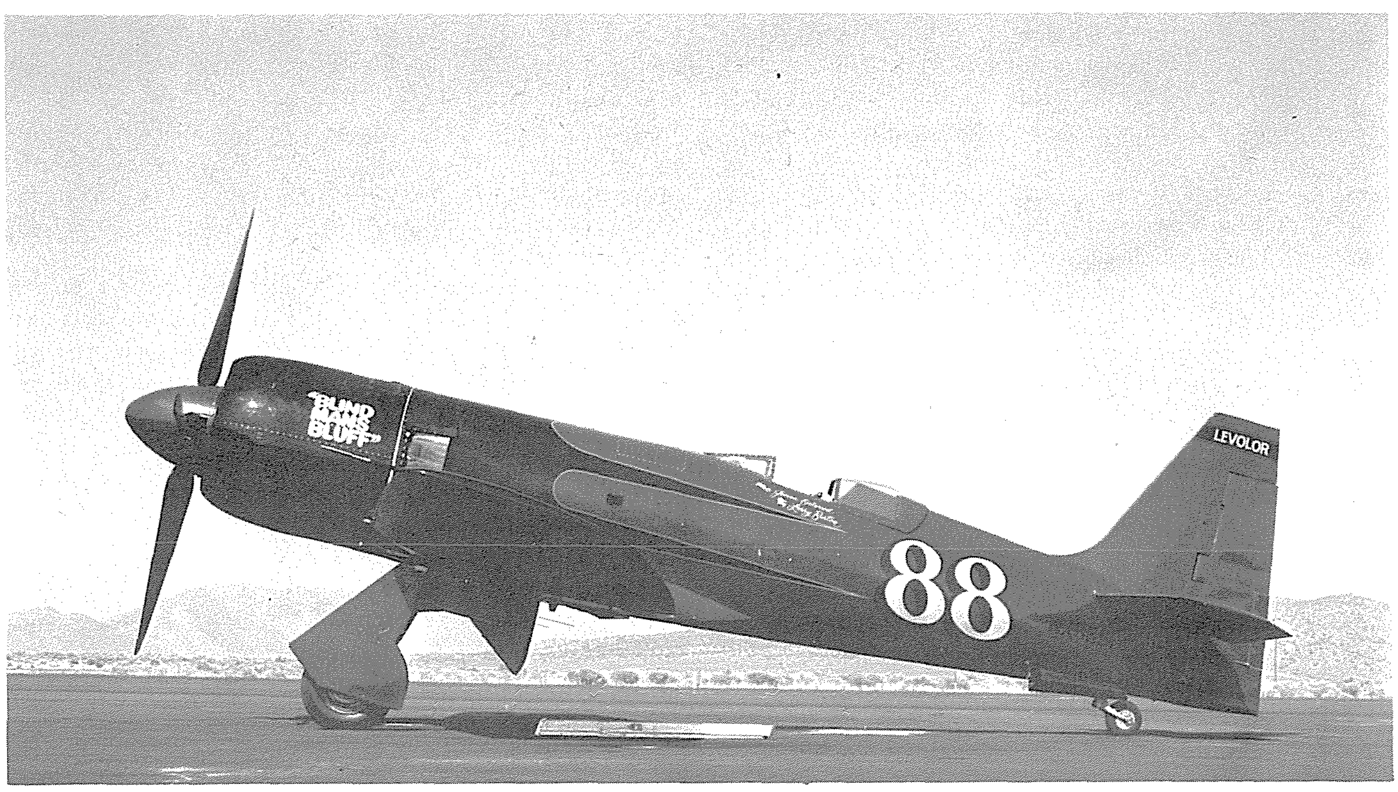
Triptane was again used during the 1949 Cleveland races. Both Bill Odom and Anson Johnson loaded this fuel into their highly modified *Merlin*-powered racers. *Aviation Week* indicated that both added four cubic centimeters per gallon of tetraethyl lead to their triptane. Not to be outdone during the 1949 races, Standard Oil offered an improved aviation gasoline with a performance number of 130/170. In essence, use of these racing fuel blends meant that engines were structurally limited and not fuel performance or detonation limited. Prolonged operation at extreme pressures and temperatures could still result in engine failure but not necessarily because the gasoline used caused detonation.

*The precise chemical nomenclature for triptane is 2,2,3-trimethyl butane. The name "triptane" was not coined until 1943.

Fuel Additives—In a broad sense, there are two convenient categories of fuel additives. The first category involves additives blended directly into aviation gasoline while the second consists of fluids introduced at some point into the engine induction system. Both categories are designed to allow the race pilot to extract more power from a highly boosted engine.

Power developed by reciprocating engines is fundamentally related to the quantity of air put through each cylinder per minute. Although both fuel and the oxygen in air are required for combustion, fuel represents only about two percent of the mixture volume. Thus the engine is essentially an air pump. Improved power output from a *Merlin* or any racing engine is accomplished by operating at increasingly higher manifold pressures through supercharging. Some attempts have been made to run *Merlin*s at compression ratios greater than the stock 6:1 ratio. Increasing compression ratio yields higher efficiency which means more energy is extracted from the charge of fuel and air introduced into the cylinders. Results from this approach have been limited. Higher manifold pressure operation is the most productive means of achieving race power output and is the technique most commonly used today. *Merlin*s are frequently raced at 100 inches of mercury manifold pressure with a high degree of reliability. Manifold pressures of 130 to 140 inches have been utilized during qualification runs and championship races.

***Sea Fury* Mk F.B. 11 modified to allow its Wright R3350 to burn methanol-nitromethane mixture. Teething problems at the 1987 Reno races resulted in replacement of the engine with a gasoline burning R3350 just prior to the races. (Birch Matthews)**



Bell P-39Q-10 *Cobra II* with pilot Tex Johnston onboard. Aircraft captured the 1946 Thompson Trophy Race. Photo shows the belly scoop oil cooler added to dissipate extra heat from race power operation.
(Bell Aerospace Corp.)

Application of these extraordinary manifold pressures can result in the phenomenon of detonation. At moderate manifold pressures, ignition of the compressed fuel mixture produces smooth stable combustion within the engine cylinders. But at higher manifold conditions, gas temperatures and pressures within the cylinders increase dramatically. Ignition and combustion of the gasoline vapor starts in a normal progression but then a threshold pressure and temperature is reached beyond which remaining unburned fuel spontaneously explodes or detonates. Consequent pressure peaks in the cylinder are extreme amounting to some three or four times a normal combustion pressure rise on the piston surface. Engine components are subjected to abnormal forces and temperatures. In the limit, structural failures occur. Detonation problems in high-performance engines can be acute as witnessed by innumerable engine failures over the years of unlimited class racing. It was the propensity of early gasolines to detonate that forced engineers to use anti-knock alcohol-based fuels in supercharged engines during the 1920s and early 1930s.

The petroleum industry attacked detonation problems by increasing the octane rating of aviation gasolines using refining and blending techniques. As noted earlier, 100-octane fuel became the standard for military aviation in this country and Britain during World War II. In addition to raising octane rating, various additives were used to retard the onset of detonation. The most commonly recognized additive is tetraethyl lead used in quantities typically one to six cubic centimeters per gallon of gasoline. Developed by Thomas Midgley, Jr., and associates, it is a remarkably effective compound.

There are many other chemical compounds capable of reducing detonation in aviation gasolines. In his classic book, *The Internal Combustion Engine,* C.F. Taylor lists 45 compounds known to have a positive effect on detonation. Standard Oil of Ohio modified its 100/130 grade gasoline provided to National Air Race competitors with aromatic compounds including benzene, toluene and xylene. These additives provided good antidetonation qualities for supercharged racing engines.

With today's military and commercial aviation emphasis on turbine engines, refinery development and production centers on jet fuels. As a consequence, racing fuel blends are the products of specialty chemical houses and not major oil companies as in the 1940s. High-performance fuel technology for present-day unlimited class racers is not significantly different from that of earlier years. Aromatic compounds such as toluene are still used to inhibit detonation.

Another additive commonly used in contemporary unlimited class racing fuels is manganese methylcyclopentadienyltricarbonyl. Because of its awesome chemical nomenclature, this compound was marketed by Ethyl Corporation under the trade name Combustion Improver No. 2 or simply CI-2. Originally used as a fuel oil additive in the electric utility industry, Ethyl Corporation hoped to expand its use as an antidetonant additive in gasolines to replace tetraethyl lead. This did not occur. Today, Ethyl markets this product under the name MMT. With MMT added to 115/145 aviation gasoline, a performance number of 170 is obtained for supercharged engine operations.

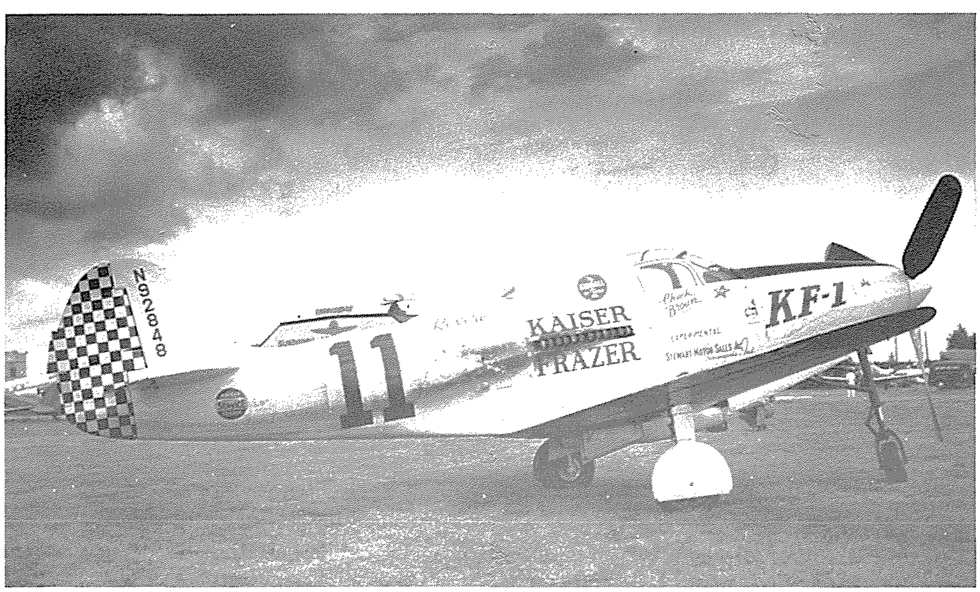
The second class of additives used in racing is not blended into the fuel. Rather, these fluids are injected directly into the engine induction system. This category includes water, nitrous oxide and nitromethane.

Water injection is virtually mandatory at high engine power levels. In reality, the fluid used is typically 50 percent mixture of water and methyl alcohol and formally called antidetonant injection (ADI) liquid. A water-alcohol mixture was originally used during World War II to prevent the liquid from freezing in cold weather climates or during high-altitude operations. This mixture has been retained for unlimited pylon racing aircraft because it yields better engine performance than straight water injection.* As ADI liquid vaporizes, incoming supercharged fuel-air mixture temperature is reduced through evaporative cooling. ADI fluid reduces engine combustion gas temperatures about 300 to 400 degrees Fahrenheit which acts to suppress detonation at high manifold pressures.

Significant quantities of ADI are required for a *Merlin* racing engine. The amount of ADI consumed during a race depends upon the engine mixture ratio setting and whether or not an aftercooler is employed at the supercharger outlet. In the absence of an aftercooler and at relatively lean mixture ratios, combustion temperatures are higher. At these conditions, ADI is used at a rate of about 0.8 to 1.0 pound per pound of fuel. A somewhat fuel-rich mixture together with supercharger aftercooling requires less ADI resulting in flow rates around 0.4 to 0.5 pound per pound of fuel. The precise amount of ADI is determined by measuring the engine air-induction temperature. This in turn is influenced by the outside air temperature. On such subtleties are races won.

*Addition of methyl alcohol is believed to result in finer atomization of the injected liquid due to a lowering of surface tension forces of the mixture in contrast with straight water. A more uniform distribution of vapor within the engine manifold is also thought to occur.

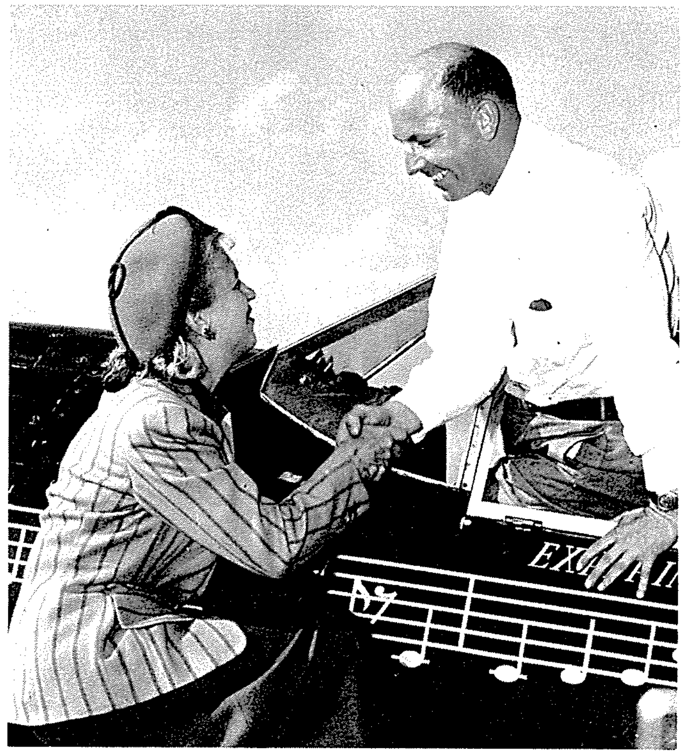
Don Noland's 1948 *Cobra* racer creation on the Thompson course. A sure winner, vapor lock in the fuel system forced pilot Chuck Brown out of the race on the 19th lap after a sterling performance. (Emil Strasser)



Bell P-39Q-10, ex-*Cobra II* reworked in 1948 to incorporate Allison V-1710G6 engine. Pre-Thompson race tests were made with methanol-based fuel. Engineer Don Noland reverted to Shell triptane fuel for the Thompson race. Added oil cooling from 1946 was retained. (Emil Strasser)

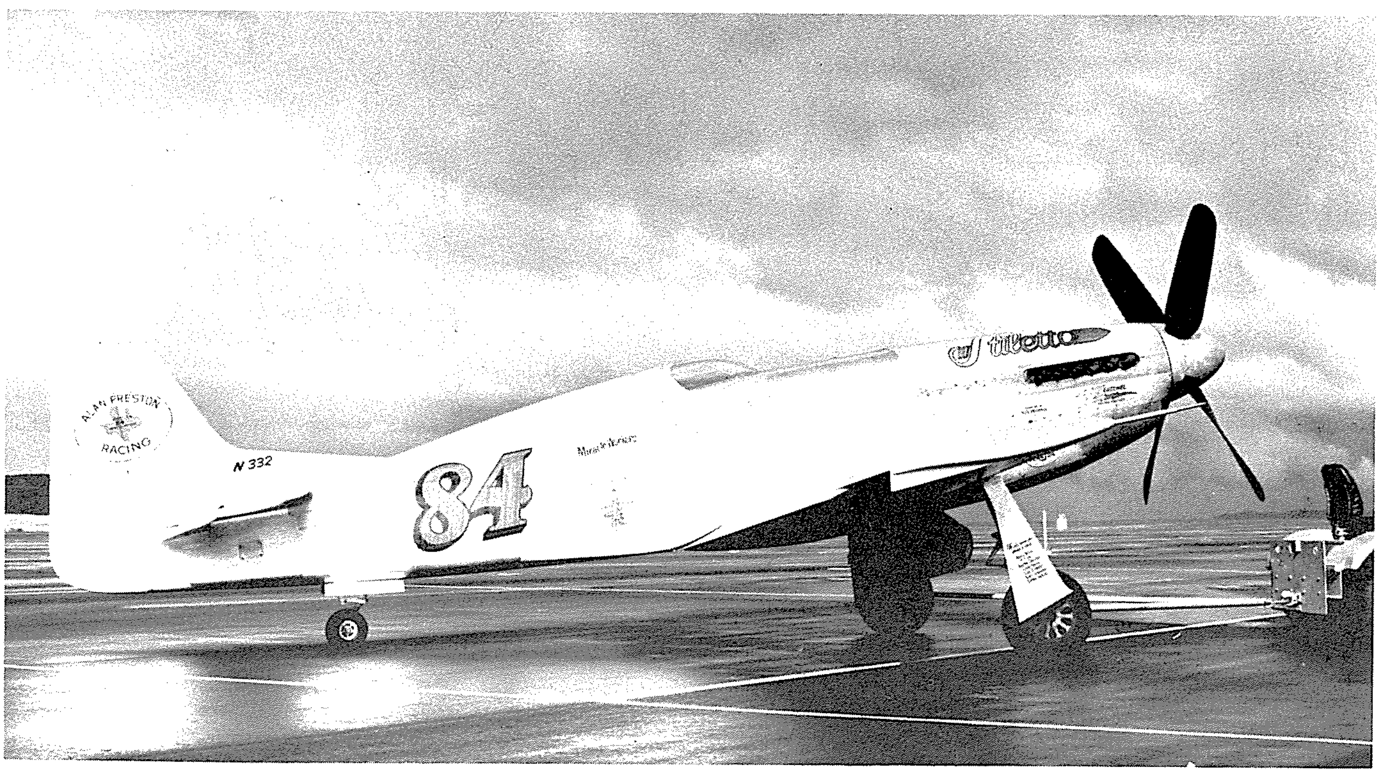
Merlin-powered unlimiteds at Reno carry around 40 gallons of ADI for the 10-minute duration championship race. By comparison, Thompson Trophy competitors used ADI at something like 0.3 to 0.5 pound per pound of fuel while operating typically at manifold pressures ranging from 80 to 110 inches of mercury. Even at lower consumption rates, Thompson pilots found it necessary to carry in excess of 100 gallons of ADI to sustain high-power levels during much of the approximately one-half-hour race. The weight penalty imposed on a *Mustang* carrying this much ADI amounted to about 800 to 1,000 pounds at race takeoff.

Another injectant periodically employed with *Merlin* engines is nitrous oxide, a compound containing about 36 percent by weight of oxygen. Injection of nitrous oxide requires additional fuel to maintain the desired engine fuel/air ratio. As a consequence, more chemical energy per charge is introduced into the engine cylinders resulting in greater power output. In addition to increased fuel input, nitrous oxide provides evaporative cooling and increased charge density. In a typical racing engine setup, liquid nitrous oxide is stored under pressure in bottles (tanks) of 24-pound capacity. In practice, the bottles are not filled to capacity and usually carry around 20 pounds of substance. This leaves sufficient tank volume available in the bottle to accept nitrous oxide vapor without venting overboard as the liquid temperature rises. The injection system incorporates on-off solenoid-operated valves controlling the nitrous oxide injection as well as added fuel flow (1.5 pounds of fuel per minute) to produce an incremental power increase of approximately 200 horsepower. Used with some restraint, nitrous oxide injection can marginally add power output to the racing engine when needed. It is advantageous for power surges in sprint situations. Used to excess or for prolonged periods, nitrous oxide injection quickly results in engine structural failure.



Jackie Cochran and Bill Odom in publicity photograph promoting her highly modified P-51B *Mustang,* "Beguine." Her *Merlin*-powered racer used Shell Oil Co. triptane fuel laced with tetraethyl lead. This powerful fuel was basically detonation free. (Robert E. Burke, Al Chute Collection)

Nitromethane is a liquid compound consisting of carbon, hydrogen, nitrogen and oxygen. Because oxygen is present in this compound, combustion is possible without the addition



Extremely modified P-51D *Mustang* racer, "Stilleto," was the creation of the late Dave Zeuschel. Like "Beguine," the engine and oil coolers were relocated into the wing. Typical of all contemporary Reno unlimiteds, spray bar cooling and ADI were used. (Birch Matthews)

Anson Johnson's highly modified P-51D *Mustang* racer at the 1949 National Air Races in Cleveland, Ohio. Engine and oil coolers were relocated to the wings. Triptane was used as fuel with a few cubic centimeters of tetraethyl lead added for good measure. (Harry Gann)

of air. The potential of "nitro" as a fuel or fuel additive has been well understood since the 1940s and indeed, has been used in other forms of motor racing. Standard Oil of Ohio reportedly offered a special antidetonant fluid to unlimited pilots entered in the Thompson Trophy Race at Cleveland. It was suggested that this particular ADI blend would result in up to 15 percent more power output from the engine. From speculation, it has been concluded that the Sohio ADI probably contained a stabilized form of nitromethane. Nitro has been used in contemporary unlimiteds including Darryl Greenamyer's F8F *Bearcat* and the Red Baron *Mustang* prior to installation of the Rolls-Royce *Griffon* engine. Reportedly, nitro was added to the aviation gasoline used in the Red Baron. Results were catastrophic in 1974. The engine exploded during the Gold Championship Race at Reno. One piston was actually blown out of the aircraft onto the desert floor and never located. It was postulated that some of the nitromethane stratified in the fuel tanks or fuel feed system resulting in an excessive amount reaching one or more cylinders. More recent applications of nitromethane have been successfully accomplished by mixing the compound with ADI solution.

Detonation Suppressing Chemical Compounds

The relentless search for fuel chemistry to suppress detonation in piston engines was eventually resolved by Thomas Midgley, Jr., and T.A. (Tab) Boyd, who empirically discovered the pacifying effects of minute quantities of tetraethyl lead in gasoline. There was more than a touch of irony in their chemical endeavors. Both were *mechanical* engineers! In his highly readable book, *I Kept No Diary,* Air Commodore R.F. (Rod) Banks relates the genesis of the Midgley-Boyd research. In 1917, America was fully engaged in "the war to end all wars." As a consequence, there was a shortage of gasoline for domestic consumption to power home generators for lighting. To offset this shortage, kerosene was distributed as a substitute. Now as it so happened, Charles (Boss) Kettering's Dayton, Ohio-based Delco Corporation was a major supplier of home lighting sets. Reacting to widespread complaints of engine knock or detonation in these devices when fueled with kerosene, Kettering turned to co-workers Midgley and Boyd with simple direction: "Find the cause; cure it." Thus began a four-year search.

According to Rod Banks, the most valuable guidance received by Midgley was provided by one Dr. Wilson of Standard Oil (Indiana) who suggested study of the Periodic Table of elemental atomic weights.* Midgley found from experimentation that compounds containing elements with higher atomic weights had better antidetonation properties. This led to consideration of metallic lead which was relatively abundant and inexpensive. The problem was then narrowed to determining a suitable organic lead compound miscible in gasoline. By 1922, Midgley and Boyd experimented with tetraethyl lead, an elemental compound consisting of carbon, hydrogen and lead. Miscible in gasoline and at very low concentration, this lead compound suppressed detonation to a remarkable degree. It was to become the basic additive to gasolines for decades to come. Using tetraethyl lead in gasoline was not without penalty. In commercial use, other additives were also necessary lest oxidized lead deposits from the combustion process result in fouled spark plugs and ruined exhaust valves. The lead deposit problem was resolved by adding two more ingredients to the recipe: namely, ethylene dibromide and ethylene dichloride.

Human health effects of lead poisoning were not unknown before World War II and there was concern with regard to the formulation of tetraethyl lead and mixing it with gasoline. Processing and handling care was exercised. It was not until recently that lead-containing products including gasoline

*The Periodic Table was conceived and produced by Dimitry I. Mendeleyev in 1896. It lists the atomic weights of all the elements. The lightest element, for instance, is hydrogen at 1.00. In comparison, lead has an atomic weight of 207.

were determined to be serious widespread air pollutants with deleterious health problems for the population-at-large.

Many additives, other than tetraethyl lead, have been evaluated for anti-knock qualities in gasoline. This is illustrated in the accompanying table. All compounds listed in this table are compared arbitrarily to aniline which carries the value of $1.00. For example, addition of 0.08 gram of tetraethyl lead would provide the same anti-knock properties as 1.00 gram of aniline. Benzene, on the other hand, would require almost 10 times as much material added to the gasoline as aniline or more than 100 times that of tetraethyl lead. Thus, the Schneider racers were running as much as 20 to 40 percent benzene mixtures during the later races. With this simple numerology, one can see how effective tetraethyl lead really was. . . .

Today's Reno unlimited racer has a very narrow range of anti-knock fuel options. Most of the compounds listed in the table are highly toxic and simultaneously strictly regulated or controlled. Benzene is a good example. Use of benzene or benzene compounds is very restricted and as a consequence it is not available in the United States as a motoring fuel. Other relatively effective additives are highly toxic such as nickel carbonyl, the selenide compounds, etc. By process of elimination either by toxicity, availability or expense, the current unlimited air racer is faced with using methanol of methanol-nitromethane mixtures, water injection and perhaps a few gasoline anti-knock additives such as Ethyl Corporation's MMT as high-performance fuel options. ■

SOURCE MATERIAL AND CREDITS

A rich abundance of technical literature exists on fuel technology for reciprocating piston engines. The subject was of vital interest to the aviation community for more than three decades. Source material for fuels and fuel additives presented here were in part derived from such basic references as Perry's *Chemical Engineers' Handbook* (McGraw-Hill, 1953), and the *Handbook of Chemistry and Physics* (CRC Press, 1985). Several other texts were quite useful: *The Internal Combustion Engine* by C.F. Taylor and E.S. Taylor (International Textbook Co., 1956), and *Elements of Internal Combustion Engines* by A.R. Rogowsky (McGraw-Hill, 1953). Valuable background information relative to the petroleum industry and aviation gasolines in particular was described in *Modern Petroleum Technology* by G.D. Hobson (John Wiley & Sons, 1973), and *Chemical Technology of Petroleum* authored by William A. Gruse (McGraw-Hill, 1960). An earlier technology perspective with respect to aviation fuels is contained in the 1936 edition of *Aircraft Engines* by A.B. Domonoke and V.C. Finch published by John Wiley & Sons. To varying degrees, all of these texts discuss the phenomenon of knock or detonation together with gasoline types less susceptible to detonation as well as additives which act to do the same thing.

The surprising history of triptane was documented in the *Journal* of the Society of Automotive Engineers (Vol. 53, No. 6, 1945) by Charles F. Kettering. Robert McClarren commented on fuels and additives used by Thompson Trophy entrants in contemporary articles published in *Automotive Industries* magazine (September 1947 and October 1948). Various articles in *Aviation Week* during the late 1940s also mention fuels used at the National Air Races.

The precise alcohol-based fuel blends (including physical characteristics) used by the British in their S.6 and S.6B Schneider racers was thoughtfully provided by technical historian Roger Huntington who obtained these data from Rolls-Royce during the late 1940s. Roger also provided insight concerning nitrous oxide injection and post-World War II fuel modifications used in Thompson Trophy racers. The authors are grateful to him for making this information available through his many letters of correspondence. Information covering the alcohol blends tested in Chuck Brown's 1948 *Cobra* racer was revealed by Allison engineer Don Noland in private correspondence, later published in the *Journal* of the American Aviation Historical Society (Vol. 8, No. 4, 1963).

In addition to the literature, a number of individuals contributed valuable information, insight and constructive comment on the subject of fuels. Retired Douglas Aircraft engineer Al Heinike consented to two enjoyable Sunday afternoon interviews on the subject of dual fuel modifications to the Maytag *Mustang.* Pilot Russ Schleeh filled in performance details together with the unhappy ending to this unique project. The 1974 methanol conversion of Bell P-63 *Miss Tipsie* was gleaned from John Sandberg via telephone interviews. An experimenter by nature, John continues at the forefront of unlimited competition with his original Tsunami racer and contemplations of a two-stroke racing engine for the future.

Also appreciated were the reviews and comments of TRW Electronics and Defense engineers Roger Baggenstoss and Dr. Christopher Shih. Lockheed engineers Bruce Boland, Pete Law and Ray Poe patiently endured numerous interviews with the authors during which the fuels, additives and injection systems used in today's unlimiteds were described. Their contributions are gratefully acknowledged. And once again, this manuscript was prepared by Shirley House through repeated drafts. Our thanks to Shirley and to all the others—past and present. . . .

ANTI-KNOCK COMPOUNDS FOR GASOLINE FUELS

Compound	Formula	Weight for a Given Effect
Aniline	$C_6H_5NH_2$	1
Benzene	C_6H_6	9.8
Toluene	$C_6H_5CH_3$	8.8
Xylene	$C_6H_4(CH_3)_2$	8.0
Ethyl alcohol	C_2H_5OH	4.75
Ethyl iodide	C_2H_5I	1.55
Diethyl selenide	$(C_2H_5)_2Se$	0.214
Diphenyl selenide	$(C_6H_5)_2Se$	0.49
Diethyl telluride	$(C_2H_5)_2Te$	0.075
Diphenyl telluride	$(C_6H_5)_2Te$	0.139
Triphenylphosphine	$(C_6H_5)_3P$	3.08
Triphenylarsine	$(C_6H_5)_3As$	2.44
Triphenylstibine	$(C_6H_5)_3Sb$	1.56
Tetraethyl tin	$(C_2H_5)_4Sn$	0.66
Tetraethyl lead	$(C_2H_5)_4Pb$	0.0295
Tetraphenyl lead	$(C_6H_5)_4Pb$	0.080
Diphenyl diethyl lead	$(C_6H_5)_2(C_2H_5)_2Pb$	0.041
Triethylbismuthine	$(C_2H_5)_3Bi$	0.135
Triphenylbismuthine	$(C_6H_5)_3Bi$	0.22
Nickel carbonyl	$Ni(CO)_4$	0.053
Dimethyl cadmium	$(CH_3)_2Cd$	1.23
Titanium tetrachloride	$TiC1_4$	0.64
Cumidine	$(CH_3)_3C_6H_2NH_2$	0.96
Diphenylamine	$(C_6H_5)_2NH$	1.21
m-Xylidine	$(CH_3)_2C_6H_3NH_2$	0.92
Monomethylaniline	$C_6H_5NHCH_3$	0.82
Toluidine	$CH_3C_6H_4NH_2$	0.94
Amylaminobenzene	$C_5H_{11}C_6H_4NH_2$	1.53
Ethylaminobenzene	$C_2H_5C_6H_4NH_2$	1.14
Aminodiphenyl	$C_6H_5C_6H_4NH_2$	1.6
Methyl-o-toluidine	$CH_3C_6H_4NHCH_3$	1.15
n-Butylaminobenzene	$C_4H_9C_6H_4NH_2$	1.44
n-Propylaminobenzene	$C_3H_7C_6H_4NH_2$	1.32
Monoethylaniline	$C_6H_5NHC_2H_5$	1.27
Mono-n-propylaniline	$C_6H_5NHC_3H_7$	1.95
Ethyldiphenylamine	$C_2H_5N(C_6H_5)_2$	3.65
Mono-n-butylaniline	$C_6H_5NHC_4H_9$	3.1
Diethylamine	$(C_2H_5)_2NH$	1.59
Di-n-propylaniline	$C_6H_5N(C_3H_7)_2$	7.15
Mono-isoamylaniline	$C_6H_5NHC_5H_{11}$	7.1
Diethylaniline	$C_6H_5N(C_2H_5)_2$	6.7
Dimethylaniline	$C_6H_5N(CH_3)_2$	6.2
Ethylamine	$C_2H_5NH_2$	2.4
Triethylamine	$(C_2H_5)_3N$	7.95
Triphenylamine	$(C_6H_5)_3N$	30.0

Notes

1. Aniline in concentrations up to 3 percent of the fuel by volume was taken as the standard or baseline effect on knock or detonation. Weight values presented are in grams and represent the amount of a given compound which must be added to a fuel to achieve an anti-knock effect equivalent to 1 gram of aniline.
2. Data excerpted from *The Internal Combustion Engine* by C.F. Taylor and E.S. Taylor (International Textbook Co., 1956).