RACING MERLINS

From Cleveland to Reno

Birch J. Matthews and Dustin W. Carter

(Following is an excerpt from the book Mustang—The Racing Thoroughbred, *being developed by the authors to document the evolution of P-51 aircraft for air racing from 1946 to the present. The complete book will recount the* Mustang *racing story from the Thompson Trophy era through present-day Reno air racing. The book is intended to portray the* Mustang*'s history in air racing with emphasis on what was done to modify the airframe and engine together with comments on the results of various endeavors.)*

Prologue—To even the most casual observer, Reno air racing is a cacophony of sights, sounds and even smells sufficient to confound the human senses. Most writers chronicling the National Championship Air Races only relate their visual recollections of the event frequently laced with statistical data to the third decimal place. But there is a story behind the sounds heard at Reno, particularly with respect to the unlimited class racers. *Mustang*s typically dominate each year's entry list. And the audio output of a racing Merlin engine under full steam is something unique. Multiplied by a full slate of entries during a Reno Gold Championship Race, the sound is truly awesome. . . . It is a sound that almost defies adequate description, but once heard is seldom forgotten. Indeed, the Merlin sound is a blend of propeller tips turning at near sonic velocities coupled with the whine of overstressed gears and staccato combustion noise. The purpose of this narrative is to provide some understanding of what is required to build a racing Merlin engine and thus give some added meaning to that wonderfully distinctive and 'awesome' sound.

MUSTANG POWERPLANTS

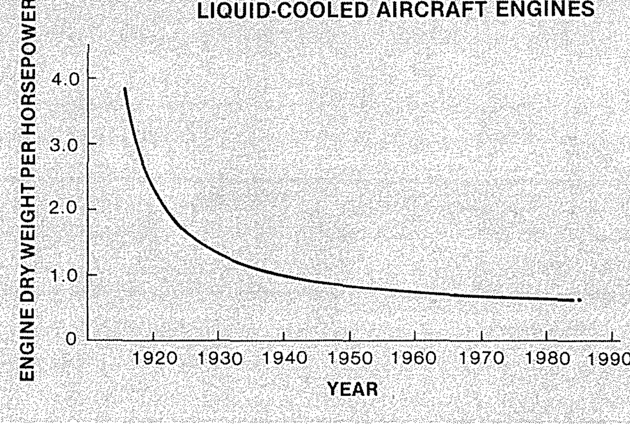
Historical Perspective—Twelve-cylinder vee-shaped liquid-cooled engines have long been used for high-speed aircraft applications. Early V-12s built by Renault appeared during World War I. Improvement of the breed was rapid during the next two decades. A figure of merit for all aircraft engines is the ratio of engine dry weight to power developed. The trend for liquid-cooled V-12s is shown in Figure 1 over a time span of 70 years. The 1916 Renault engine produced 220 horsepower and weighed over 800 pounds. The weight-to-power ratio was 3.66. As early as 1920, V-12 engines had an improved ratio of around 2.3 and the advent of World War II brought this figure to near unity. Preeminent in this respect was the Rolls-Royce *Merlin* engine. Contemporary Reno unlimited pylon racers using *Merlins* achieve a weight-to-power ratio of less than 0.6, a rather astounding value for World War II vintage engines.

Although the apparent tangle of metal, plumbing, cable and wiring under the cowling of a *Mustang* may appear complex, the fundamental processes of piston engine operation are relatively straightforward. A mixture of fuel and air called a "charge" is inducted into each engine cylinder. The charge is compressed by a piston and ignited by firing a spark plug. High-temperature combusting gases expand and force the piston downward to the end of its stroke. Linear motion of the piston is translated by a connecting rod into rotating movement of the crankshaft. When the power stroke is complete, the piston reverses direction and forces residual exhaust gases out of the cylinder exhaust valve ports. This process is repeated when the pistons once again move downward drawing fresh charge into the cylinders through intake valve ports. Crankshaft counterweights provide the necessary balance and momentum to maintain rotation between piston power strokes.

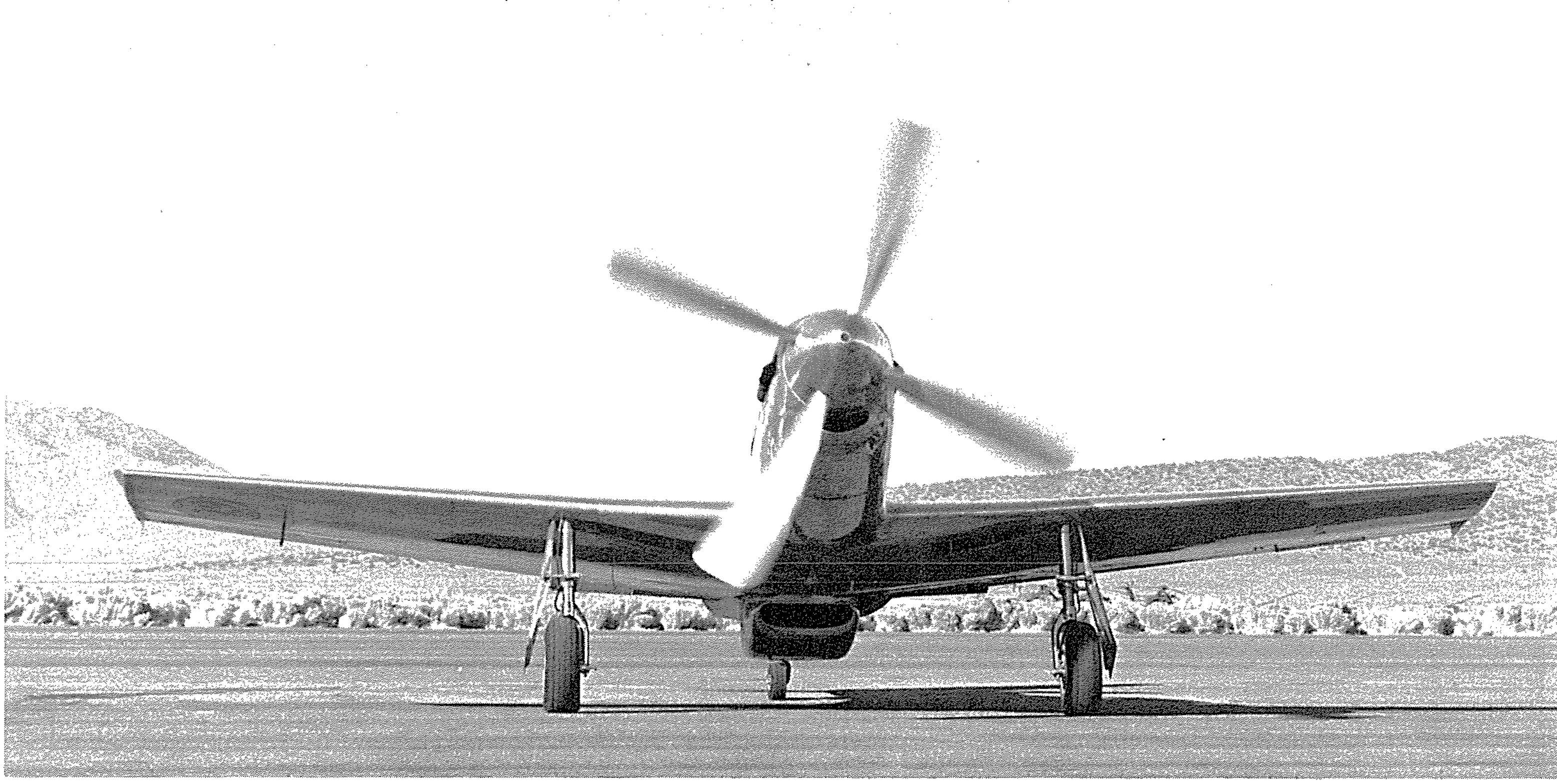
The process just described is termed a four-stroke cycle and as indicated, consists of intake, compression, combustion (power) and exhaust piston strokes. Rolls-Royce chief engineer and superb aerodynamicist, Sir Stanley Hooker, once facetiously remarked that "the four-stroke engine has one stroke for producing power and three for wearing the engine out." Before the advent of aircraft gas turbines, however, the four-stroke piston engine was without peer.

Fuel-air mixture ratio varies depending upon desired

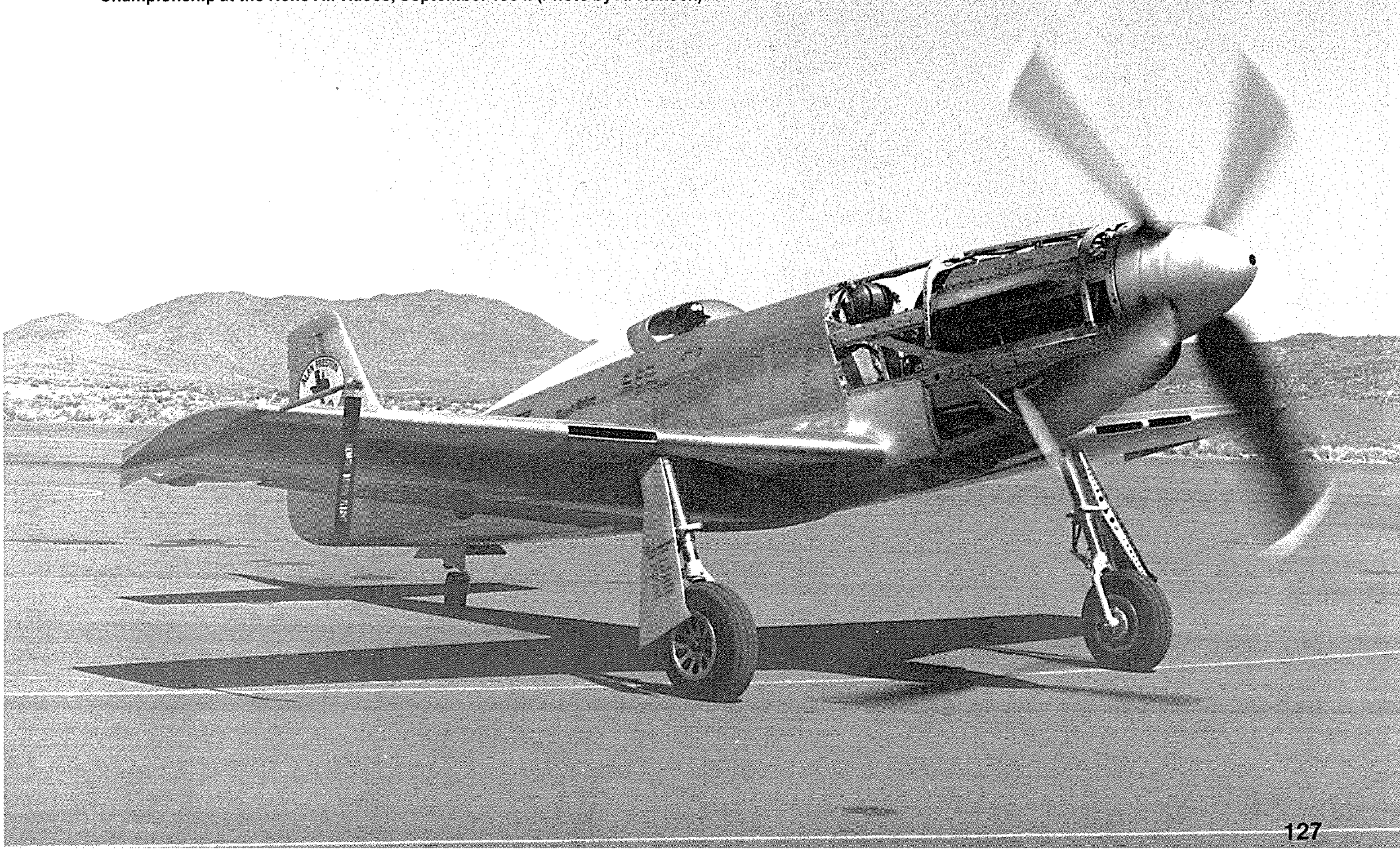
Figure 1 — PROGRESS IN WEIGHT REDUCTION PER HORSEPOWER FOR V-12 LIQUID-COOLED AIRCRAFT ENGINES



The business end of a P-51D racing *Mustang* is illustrated in this view of Don Whittington's *Precious Metal.* Race 09 was a frequent entrant at Reno during the late 1970s and held the qualifying record at one time.
(Photo credit: Birch Matthews)



Modified North American P-51D, N332 *Stiletto* after winning the Unlimited Championship at the Reno Air Races, September 1984. (Photo by Al Hansen)



engine operation. To achieve maximum power, a fuel-air ratio of about 0.09 is required. At this ratio, one pound of gasoline is mixed with 11 pounds of air. If the weight of air processed by an engine is increased per unit of time, power output will be proportionately higher because more fuel (chemical energy) is simultaneously added to maintain constant mixture ratio.

Early aircraft engines were "normally aspirated" in that charge air was drawn from the local atmosphere. At sea level, weight density (pounds per cubic foot) of air is at a maximum. Air density decreases as altitude above sea level increases depending upon local barometric pressure and temperature conditions. Thus, power output of normally aspirated engines is reduced with increasing altitude because air density is diminished. To overcome this inherent limitation, charge air must be compressed to maintain or increase the weight of air processed by the engine. Different types of compressors have been employed to increase air pressure supplied to aircraft piston engines; however, the centrifugal blower is most widely used. Blowers are commonly called superchargers, a name derived from the basic terminology for the fuel-air mixture or 'charge' supplied to a piston engine. Supercharger technology developed rapidly during the late 1920s and the decade that followed. The capacity of the basic *Merlin* engine design to accept increasing degrees of supercharging was perhaps its greatest single attribute. At conception, the *Merlin* produced something in excess of 800 horsepower. By the end of World War II, *Merlin* variants developed more than 2,000 horsepower. Current racing *Merlins* have generated slightly over 3,000 horsepower.

The Merlin Heritage—The driving force behind the Rolls-Royce firm was Sir Henry Royce. A meticulous craftsman of humble origins, Royce's interest in the fledgling automobile business eventually brought him in contact with C.S. Rolls, pioneer balloonist and auto racer. The two men formed Rolls-Royce Ltd. to produce the finest quality motor cars in the world.

It was C.S. Rolls, however, who first became intrigued with flying heavier-than-air machines. Coincidentally, he rapidly lost interest in automobiles. In 1910, Rolls made the first double crossing of the English Channel in an airplane. Tragically, he was killed on 12 July of that same year during a flying meeting in Bournemouth, England. Structural failure in the French-built *Astra Flyer* he was piloting resulted in a fatal crash. Frederick Henry Royce, conversely, did not share his colleague's interest in aviation and Rolls' accidental death had a profound effect upon him. Royce gave no thought to aviation ventures. One wonders if Rolls-Royce Ltd. might have built airframes as well as aircraft engines had C.S. Rolls lived.

World War I brought the company into design and manufacture of aircraft engines. This led to the Rolls-Royce *Eagle* series, first in a long line of engines named for birds of prey. The *Eagle* was followed chronologically by the *Hawk, Condor, Kestrel* and *Buzzard* engines.

In 1928, Rolls-Royce discussed the possibility of using their engines in airframes contemplated by both Supermarine and the Gloster Company for the 1929 Schneider Trophy Race. Britain's Air Ministry finally guaranteed government support for the race in late February of 1929. This decision having been made, Supermarine accepted Royce's proposal. It was a fortuitous acceptance for both companies. The racing engine series developed by Rolls-Royce was truly a progenitor of the *Merlin* engine. Supermarine's aerodynamic efforts ultimately led to the *Spitfire,* a World War II benchmark in fighter aircraft.

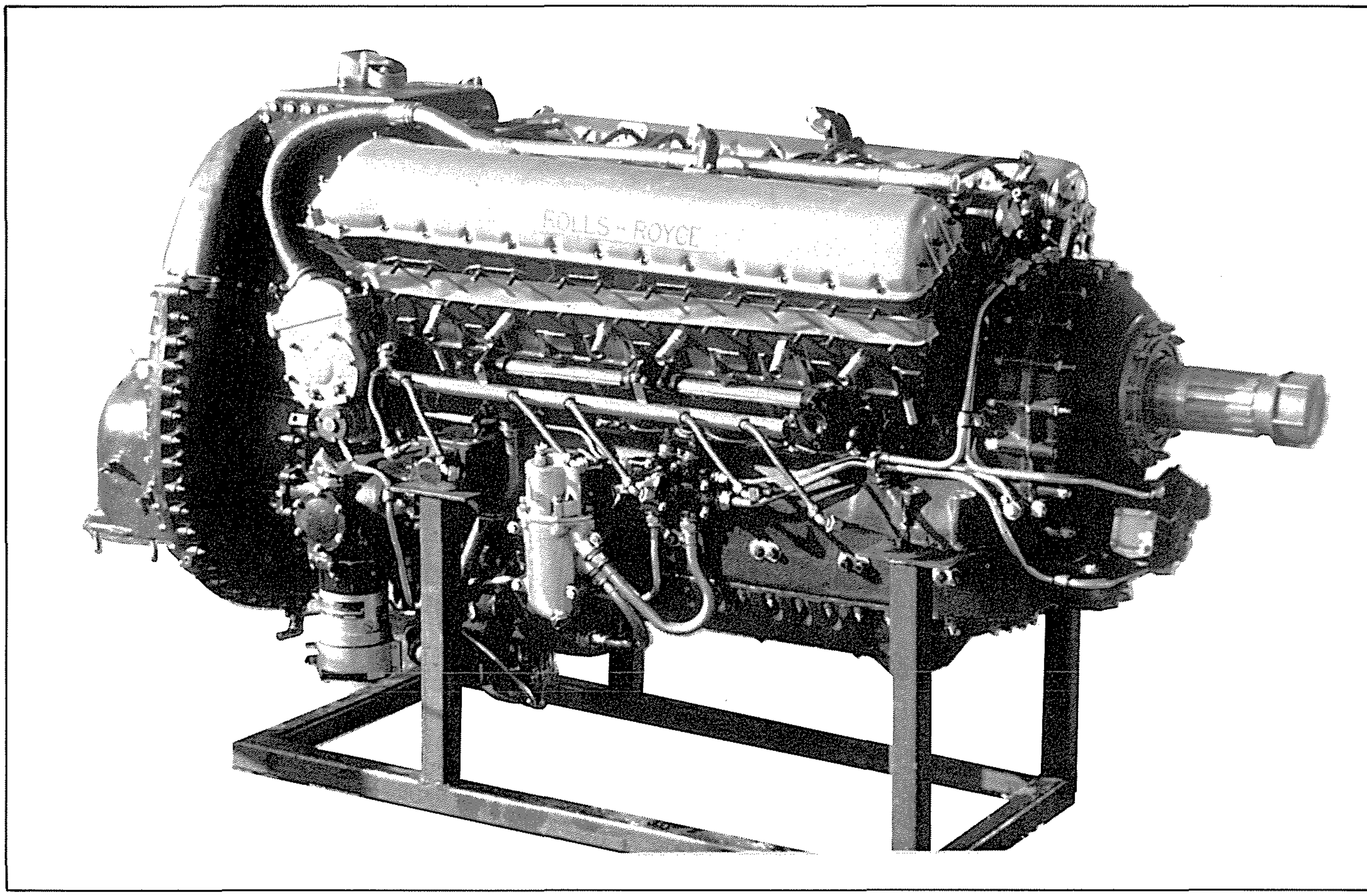
The approach selected by Royce for the 1929 Schneider Trophy Race was to modify and supercharge a normally aspirated 825-horsepower *Buzzard* engine. The end product was the Rolls-Royce R engine which produced about 1,900 horsepower and powered a Supermarine S.6 racing floatplane to victory in the Schneider race. In 1931, the Schneider Trophy Race was held for what was to be the final time. Rolls-Royce engineers improved the R series engine until it was capable of 2,300 horsepower. Installed in the 1931 Supermarine S.6B racer, this combination won permanent possession of the Schneider Trophy for Great Britain.

Rolls-Royce engineering evolved a truly elegant solution to increasing power of the *Buzzard* engine. The heart of this dramatic power increase centered on adapting a two-sided centrifugal blower to increase the mass flow of air processed by the engine. This, coupled with more rugged construction and an exotic fuel blend, resulted in a winning combination.

As 1932 drew to a close, Rolls-Royce realized that advances made with their *Kestrel* engine series together with the R engine experience provided a basis for a new design that promised world leadership in liquid-cooled aircraft engines. This new concept centered on a 1,650-cubic-inch displacement design initiated as a private venture.* Design of what was eventually to become the *Merlin* began two years after the Allison V-1710 engine development commenced in the United States. Clearly similar in dimension and displacement, the Allison never matched its British counterpart in performance. The *Merlin* engine resulted from a confluence of three factors: two decades of engine development experience; a workforce dedicated to quality craftsmanship; and, technical leadership molded by Sir Henry Royce. Ironically, Sir Henry suffered failing health during this period and his direct involvement in what was to become the company's most famous aircraft product, was limited. Frederick Henry Royce died on the 22nd of April 1933.

The burden of developing the *Merlin* fell to the talented Rolls-Royce staff including A.G. Elliot and E.W. Hives. What resulted was a liquid-cooled aircraft engine composed of 12 cylinders in two 6-cylinder banks separated by 60 degrees included angle. The bore and stroke of each cylinder was 5.4 inches and 6.0 inches respectively, for a total displacement of 1,650 cubic inches of swept volume. By comparison, the Allison incorporated a 5.5-inch bore with a stroke of 6.0 inches yielding a displacement volume of 1,710 cubic inches. Compression ratio for the *Merlin* was 6:1 while

*Virtually all historians recount the fact that the *Merlin* engine began as a private venture with corresponding Rolls-Royce nomenclature of P.V.12. In most instances, the reader is allowed to infer that the British Air Ministry had little if any interest in the project. Major G.P. Bulman, Ministry of Supply and a Fellow of the Royal Aeronautical Society, commented ". . . [the *Merlin*] began without Air Ministry support. Well, the support was offered but it was not accepted. The firm prepared to go ahead with it as a private venture, no doubt because they thought they would be free to deal with ultimate royalties and so on, but it was not long before they came along and said, 'We will accept your offer of a contract,' and got it." Whatever the circumstances, development of the *Merlin*, named after a member of the falcon family of birds, proceeded boldly.



Packard-built Rolls-Royce *Merlin* engine in the pit at the Reno Air Races. Note the two-stage supercharger housing at the rear of the engine. (Photo by Al Hansen)

the Allison was 6.65:1. Output for the early *Merlin* series was 880 horsepower at 3,000 crankshaft revolutions per minute (rpm). By the end of World War II, production variants of the original *Merlin* achieved maximum outputs in excess of 2,000 horsepower, more than twice the original power output with the same displacement. The approach to achieve this remarkable power increase was essentially that utilized by Sir Henry in evolving the Schneider Trophy Race R engines; namely, supercharging and structural refinement. The *Merlin* benefited from the R engine development through use of stronger components in part aided by improved metal alloys, sodium-cooled exhaust valves, improved spark plug design and use of exhaust gas discharge to augment total thrust. This latter element took advantage of energy remaining in the high temperature, sonic velocity engine exhaust gases. Allowing these gases to exhaust through properly designed stacks added measurable thrust. What evolved from all this was the epitome of liquid-cooled engine development for that era and a basis of even greater *Merlin* power for future unlimited class air racing.

Postwar Unlimited Class Racing: 1946-1949—With resumption of air racing in 1946, ascendancy of Rolls-Royce designed engines commenced. Early dominance of *Merlin*-powered *Mustangs* occurred in the long-distance Bendix Trophy Race. Both Paul Mantz and Joe DeBona rode *Mustangs* to victory in the Bendix. Indeed, *Merlin*-engined *Mustangs* dominated this classic race. *Mustangs* also won the closed-course Tinnerman, Kendall and Sohio Trophy races of that period. And in 1948, Anson Johnson won the premier Thompson Trophy Race in a D model *Mustang* using a dash 225 *Merlin* engine.

In those early years after World War II, variants of both the *Merlin* and Allison engines powered *Mustangs* in the postwar races. These are listed in the accompanying tabulation (Table 1). Many pilots simply ran these engines in stock condition at or near war emergency power. A venturesome few modified *Merlins* to operate at higher manifold pressures and crankshaft speeds (rpm). In comparison with current day practice, such modifications were relatively modest. Nonetheless, *Merlin* reliability and durability in pylon races proved a problem during this era.

Bendix Trophy *Mustangs* faired much better. In this race, the objective was to fly nonstop at or near emergency power, a goal few could achieve. War emergency power in the military meant a maximum engine manifold pressure and speed for a specified time limit; typically not to exceed five minutes. For example, the Packard-built V-1650-7 *Merlin* had a 19,300-foot critical altitude war emergency rating of 1,500 horsepower at 67 inches of manifold pressure and 3,000 revolutions per minute.* The dash 9 Merlin could produce significantly more horsepower at a greater critical altitude but only through use of water injection. The weight and volume of water required for the 2,000-mile Bendix race made this alternative impractical.

The capacity of the *Merlin* to absorb supercharging and

* Critical altitude is the maximum altitude at which a supercharged engine can deliver full sea level power. Data obtained from "Performance Calculations for Model P-51D Airplane," North American Aviation, Inc., Report No. NA-46-130, 6 February 1946.

TABLE 1 — VARIOUS ENGINES USED OR MODIFIED FOR RACING MUSTANGS

Engine	Max. Power H.P.	Max. Power RPM	Reduction Gear Ratio	SUPERCHARGER Impeller Dia. 1st Stage	SUPERCHARGER Impeller Dia. 2nd Stage	SUPERCHARGER Gear Ratio Low	SUPERCHARGER Gear Ratio High	Remarks
V-1650-3	1600	3000	0.479:1	12.0"	10.1"	6.391:1	8.095:1	Used on P-51B and P51-C through –10 variants. Also used as a replacement on later P-51D aircraft.
V-1650-7	1720	3000	0.479:1	12.0"	10.1"	5.802:1	7.349:1	Production P-51D models.
V-1650-9	1930	3000	0.479:1	12.0"	10.1"	6.391:1	8.095:1	Equipped with water injection (ADI) system. Similar to V-1650-J.
Merlin 225	1620	3000	0.420:1	10.25"		8.15:1	9.49:1	Single-stage, two-speed supercharger. Engine equipped Canadian-built de Havilland Mosquito.
Merlin 500	1635	3000	0.420:1	10.25"		8.15:1	9.49:1	Single-stage, two-speed supercharger used in York and Lancastrian transports.
Merlin 620	1800	3000	0.471:1	12.0"	10.1"	5.79:1	.7.06:1	Two-stage, two-speed supercharger. The 600 series of engines was produced in eight variants. The 620 is representative and powered the DC-4M-1 and Canadair North Star transports.
V-1710-81	1330	3000	0.500:1	9.5"		8.800:1		Single-stage, single-speed supercharger. P-51A engine.
V-1710-87	1500	3000	0.500:1	9.5"		7.480:1		Single-stage, single speed supercharger. A-36A engine.
Griffon	2450	2750	0.442:1	11.5"	13.4"	5.84:1	7.58:1	Griffon engine used in the Red Baron RB-51 was a hybrid composed of Griffon 57 and 74 components, the latter providing a two-speed, two-stage supercharger. The Griffon 57 nose case afforded the contra-rotating propeller shafts. Stock Griffon 74 blower gear ratios are quoted. Custom gearing was used for the RB-51.

deliver in excess of 1,500 horsepower at altitudes approaching 20,000 feet made it a very competitive engine for the Bendix race. Equally impressive, however, was the ability of this engine to operate at war emergency power continuously during the approximately four and one-half hours required to fly the Bendix. Such prolonged maximum power operation was not without precedent. Wartime development resulted in numerous *Merlin* durability tests. For example, the Army Air Force ran a dash 7 *Merlin* for three and one-half hours at 67 inches manifold pressure and 3,000 rpm during tests to evaluate engine operation at elevated oil temperatures.

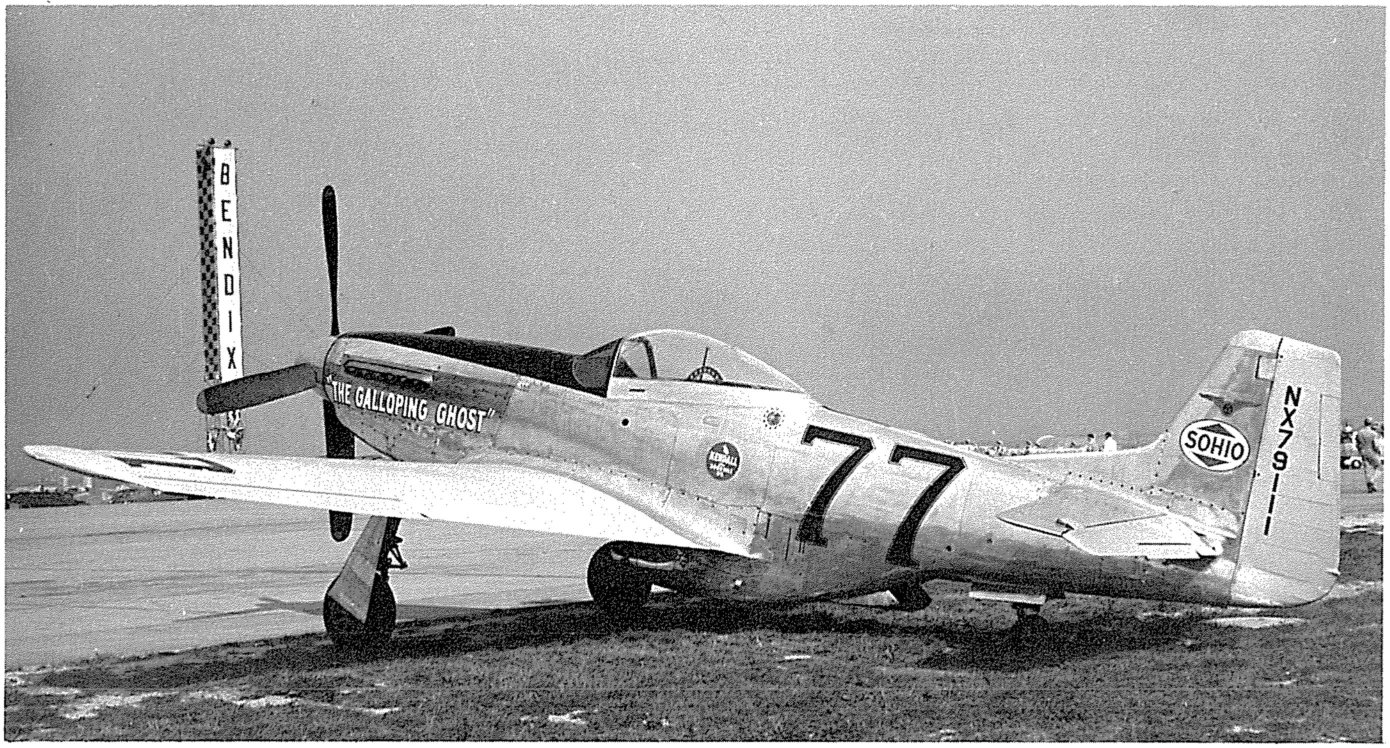
The rigors of pylon racing offer a challenge different from transcontinental events. Such events are run at low altitude for relatively short durations. Competitive engine configurations will vary depending upon such factors as local race duration, altitude and weather conditions. Pylon race distances have varied significantly during the past 40 years (Table 2). Longest were the California 1000 and U.S. Cup Races held during the early 1970s. Shortest are the current Reno Championship races. Race distance determines the amount of fuel and oil which must be carried and the extent of water injection which may be utilized. In contemporary Reno Championship races, *Merlins* operate continuously at maximum water injection rates for this relatively short race. *Merlin*-powered *Mustangs* in the Thompson Trophy Race were limited to water injection rates of 40 to 60 percent of current practice with correspondingly lower power settings. The Thompson race was four times longer than Reno's Championship Gold Race. Conversely, later 1000-kilometer (621-mile) and 1,000-mile pylon races during the 1970s did not preclude use of water injection because pit stops were accomplished. Both Howie Keefe and Darryl Greenamyer utilized water-injected *Merlins* during the California 1000 and U.S. Cup Races, respectively.

Table 2 — COURSE DISTANCE FOR VARIOUS PYLON RACES

Event	Distance—Miles	Remarks
California 1000	1,000	1970 only
U.S. Cup Race	1,000	1971 only
California 1000	621	1,000 kilometers in 1971
Thompson Trophy	300	1946 through 1948
Sohio Trophy	240	1946 only
Thompson Trophy	225	1949 only
Sohio Trophy	105	1947 through 1949
Kendall Trophy	105	
Tinnerman Trophy	105	
Reno Championship	73.8	See note

Note: Length of the Reno unlimited race course has varied eight times since inauguration in 1964 when the original course length was 80 miles. The longest was the 1968 race of 12 laps totaling 96 miles. The shortest was the 1980 eight-lap race of 72 miles.

The host site for a pylon race determines the altitude in which an engine must operate. Air density diminishes with altitude and thus the weight flow of air processed by an engine decreases. Supercharging is the antidote; however, it is not without cost. Engine-driven superchargers on *Merlins* consume about 600 to 1,000 horsepower at race operating conditions. Each stage simultaneously imposes a weight penalty on the airframe. Thus at postwar events in Cleveland, a two-stage setup on a *Merlin* could prove a liability with a net power loss and weight handicap in a race run at near sea level conditions. For this reason, at least three *Mustangs* at Cleveland in 1949 ran a low-altitude *Merlin* 225 engine employing a single-stage supercharger. These were Anson Johnson's highly modified N 13Y, M.W. Fairbrother's N 65453 and James Hagerstrom's N 37492. The *Mustang* flown by James Hagerstrom, N 37492, race 37, during the 1949 races was indeed equipped with a dash 225 *Merlin*. The entry form submitted by J.D. Reed for this aircraft listed the engine



North American P-51D, NX79111, *The Galloping Ghost*, at the National Air Races in Cleveland, Ohio, in 1947. This aircraft is still active in air racing. (Peter M. Bowers Photo)

as a *Merlin* 225, serial number V-344027.

By contrast, Reno-Stead Airfield—host of the current unlimited classic—is situated at a 5,000-foot altitude. Competitive *Mustangs* typically run two-stage *Merlin* superchargers. Assessing the degree of supercharging necessary for a given race location is shown in Table 3. Derived from International Civil Aviation Organization (ICAO) data for a standard atmosphere, this shows that in theory an engine racing at Reno requires an additional 20 cubic feet of air for each pound of fuel burned compared to the same engine running at Cleveland in the Thompson. Actual local atmospheric conditions will vary but race site location plays a prominent role in determining the engine setup.

Table 3 — AIR VOLUME REQUIRED PER POUND OF GASOLINE AT STANDARD ICAO ALTITUDES MIXTURE RATIO = 0.09

Location	Altitude	Air Density (lb/ft^3)	Required Air Volume (ft^3)	Percent Increase (%)
Schneider Trophy Race	Sea Level	0.0765	145	—
Thompson Trophy Race	800	0.0747	149	3
California 1000 Race	3,000	0.0700	159	9
Reno Air Race	5,000	0.0659	169	16
Bendix Trophy Race	25,000	0.0343	324	123

Contemporary Unlimited Class Racing: 1964-Present— Early years at Reno frequently saw basically stock *Mustangs* with unaltered dash 7 or dash 9 *Merlins* in competition. There were exceptions, of course, including the *Mustangs* of Chuck Lyford, Chuck Hall and later, Gunther Balz. This first decade of contemporary racing produced some *Merlins* modified with lightweight pistons, increased compression ratios and emphasis on improved fuel distribution. Manifold pressures up to 100 inches of mercury were possible with a dash 9 engine speed of 3,100–3,200 revolutions per minute. A dash 9 *Merlin* was probably the most popular variant. Water-alcohol injection became routine. Nitrous oxide was employed by several pilots.

During these years, *Merlin* engines strained to the limit attempting to match the Grumman *Bearcats* of Darryl Greenamyer and later Lyle Shelton. There were some closed-course *Mustang* victories during this period of air racing revival. Indeed, Clay Lacy was the first *Mustang* pilot to capture the unlimited gold race at Reno. It was not until 1972 that a highly modified *Mustang* and custom-built *Merlin* succeeded to the winner's circle in the Reno Gold Championship Race. This honor went to Gunther Balz. He demonstrated that a *Merlin* could indeed provide the power and durability necessary to surpass more powerful radial-engined *Bearcats*.

The engine in Gunther Balz's racer used cylinder heads and banks from the more rugged *Merlin* 620 transport engine combined with a dash 9 engine crankcase and supercharger. The reduction gear ratio was lowered to inhibit propeller tip speeds reaching sonic velocity while running the *Merlin* at high revolutions. This philosophy of mixing and matching assemblies from various *Merlin* marks and Packard dash numbers is now a competition standard.

Engine Modifications—What follows is a generic description of modifications to *Merlin* racing engines. Engine rebuilders differ somewhat in detail over what constitutes an optimum racing setup but for the most part such variations are subtle in extent. Starting at the ground floor, both Packard and Rolls-Royce transport engine cases (crankcases) are used. Attached to the rear of the engine case is a wheelcase housing gear drive trains necessary to engine operation. Table 4 lists drives located in the wheelcase of a stock V1650-7 engine together with corresponding gear ratios. Maximum engine speed for military-rated *Merlins* is 3,000 revolutions per minute (67 inches manifold pressure). At this crankshaft speed, camshafts are geared to rotate at 0.5 x 3,000 or 1,500 revolutions per minute. At engine overspeeds of 3,200 to 3,800 revolutions, a camshaft still only rotates at 1,600 to 1,900 revolutions per minute, an acceptable limit. Similarly, most engine pumps are turning at approximately 2,500 to 3,000 revolutions compared to their original design maximum of about 2,400 revolutions per minute. Experience has demonstrated that these accessory components are capable of withstanding overspeed operation for at least limited Reno race durations. An exception is the electrical generator with a gear ratio of 2.468:1. For an engine speed of 3,000 revolutions, the generator turns 7,400 revolutions each minute. During a race with an engine speed of say 3,400, a generator speed of 8,390 revolutions results. In earlier years at Reno, such generator speeds led to armature wire failure and floating armature brushes. Conversion to alternators with rotating armatures alleviated this problem, though high alternator drive speeds together with engine-induced vibrations still cause difficulties.

Table 4 — WHEELCASE GEAR DRIVERS: V-1650-7*

Component	Gear Ratio	Remarks
Camshaft	0.5 : 1	
Front Scavenger Pump	0.814 : 1	
Rear Scavenger Pump	0.814 : 1	
Oil Pressure Pump	0.814 : 1	
Hydraulic Oil Pump	0.819 : 1	
Engine Coolant Pump	1.5 : 1	
Engine Fuel Pump	0.6 : 1	
Generator	2.468 : 1	Alternators now used
Electric Starter	104.252 : 1	Not used on Stilleto**
Aftercooling System Pump	1.892 : 1	Sometimes not used
High Blower	7.349 : 1	Dash 9 ratio = 8.095 : 1
Low Blower	5.802 : 1	Dash 9 ratio = 6.391 : 1
Magneto Drive	1.5 : 1	
Auxiliary Drive (Exhaust Side)	0.777 : 1	
Auxiliary Drive (Intake Side)	0.828 : 1	
Auxiliary Drive (Intake Side)	1.0 : 1	
Tachometer	0.5 : 1	

*Data obtained from "P-51D Fighter Airplanes," Report No. NA-8248, North American Aviation, Inc., December 1944.
**The starter was removed as means of saving weight. A portable electric starter was instead used to drive the engine hard crank adaptor.

Behind the wheelcase is the supercharger which compresses charge air delivered to the cylinders. Competitive *Merlins* at Reno supercharge to manifold pressures well over 100 inches of mercury. Veteran unlimited pilot Jimmie Leeward has run his engine at 135 inches and 3,800 revolutions although he freely admits that *Merlin* durability becomes problematic. At 100 inches, Jimmie notes that "*Merlins* are very durable." Lockheed engineer Bruce Boland states that Reno championship class unlimiteds with a dash 7 supercharger can run at power settings of 110 inches and 3,600 rpm to 120 inches at 3,800 rpm." Supercharging is discussed further in Appendix A.

Most *Merlin*-powered *Mustangs* raced at Cleveland and at Reno have used two-speed, two-stage blowers, typically from the Packard dash 7 or dash 9 engine. All run in low blower. This allows overspeed engine operation (increased power) without the additional power loss incurred running the blower at high speed. The two-speed single-stage blower from a *Merlin* 225 engine was successfully run at Cleveland during the late 1940s. At Reno, however, the mile-high air density makes the single-stage blower running in high speed inadequate. Manifold pressures above 85 inches of mercury are virtually impossible.

During the early years of Reno air racing, the dash 9 supercharger was popular. Engine speeds were more modest typically running in the 3,100 to 3,400 revolutions per minute range. As engine speeds increased in the never-ending quest for more power, dash 7 blower gears became favored. The dash 7 gear ratio is lower than the dash 9. Consequently, this configuration runs at slower speeds and less horsepower is consumed by the supercharger.

All competitive engine builders weld additional mass to *Merlin* crankshaft counterweights for dynamic balance at high speed. Rolls-Royce crankshaft counterweights thus modified have been known to fracture at race speeds. Conversely, Packard-built crankshafts seem less prone to this failure. Postwar transport engine series crankshafts are somewhat more rugged also and are used extensively for racing. It is believed that these later series components benefited from improved metallurgy through development extending into the 1950s.

Huskier connecting rods from transport engines are also favored for racing. Rods are shot peened to increase fatigue life for improved durability.* Connecting rod bolts are heat treated to obtain a four to five percent increase in hardness. All critical steel parts are carefully inspected using the Magnaflux process. This process relies upon magnetic properties found in most steels. Imperfections in the surface of a forged steel connecting rod or crankshaft result in discontinuities in the applied magnetic field used in this inspection method.

Another *Merlin* modification involves use of Allison V-1710 connecting rods in place of Rolls or Packard rods. This substitution is possible because both engines have identical 6.0-inch piston strokes. First employed in boat racing engines, the conversion to Allison rods is expensive as custom connecting rod bearings must be built to make the adaptation. The advantage obtained is greater structural strength to withstand high-speed loads imparted to the connecting rods during race operation. The Allison connecting rods are larger and stronger than their *Merlin* counterparts.

At the top end, engine builders frequently use transport series heads and banks. Stronger construction and apparently improved metallurgy of these late-model engines provide sought-after qualities for racing. An advantage with transport heads is elimination of the soft aluminum head gaskets which provide a gas seal between the heads and cylinder liners of earlier Packard and Rolls engines. Transport series heads are sealed against the cylinder liners using ground and lapped surfaces.

Transport engine heads possess the additional advantage of having intake and exhaust valve openings about five percent larger than military engine heads. This provides better engine breathing when introducing fresh charge and exhausting combusted gases. Of available transport heads, 600 series components are the most desirable. The 500 series *Merlins*

*Shot peening is a surface treatment which increases the compressive strength of the metal.

utilized a single-stage supercharger and developed lower rated horsepower relative to the two-stage 600 series engines. Race experience demonstrated that 500 series heads are prone to cracking between the intake valve seats when subjected to race power outputs. Both Rolls and Packard heads are used for racing. Packard heads are superior in one respect. Transport head perimeter tiedown studs are relatively easy to pull out. As a consequence, virtually all transport heads use helicoil inserts. These are seldom required for Packard components. This difference between Packard and Rolls heads is again attributed to subtle variations in metallurgy or the casting process.

An alternative engine head configuration developed by the late Dave Zueschel involves welding filler into the seal counterbore on Packard dash 9 heads. The surfaces are then machined and lap finished. A dash 9 cylinder skirt is used in conjunction with 500 series liners. Thus the propensity of 500 series transport heads to crack under stress loads due to high-speed operation is eliminated; however, the improved head seal configuration is retained. Innovations such as this help keep 40-year-old engines operational.

In a similar fashion, cylinder liners can be reworked for continued use. Liner hardness is an important factor with respect to wear from continued translation of the piston and rings. Rolls-Royce greatly improved the hardness of transport liners over that achieved for their military engines. The 600 series liners achieved the highest hardness values approaching that of chromium. Indeed, chrome alloy piston rings must be carefully run in to obtain proper seating of the ring.

Very early engines coupled the propeller directly to the crankshaft. Engine speeds rapidly increased as development proceeded and propeller structural loads due to centrifugal force quickly became excessive. For this reason reduction gear drives are used to slow the propeller speed relative to the crankshaft. Propellers convert engine shaft horsepower into propulsive thrust. In general, large diameter propellers are more efficient in that they process large masses of air flow. As engine speeds increase, propeller tip velocities approach the speed of sound. At sonic velocity, propeller efficiency drops rapidly. Indeed, the propeller begins to act as a brake on aircraft forward velocity even with increased engine power output. For this reason, racing aircraft often use propellers of somewhat shortened diameter to forestall onset of sonic velocity at the tips. This approach has decided limits with respect to propeller design and efficiency.

Reasonable propeller tip velocities are obtained by lowering the reduction gear drive ratio. Stock Packard dash 7 *Merlins* use a reduction gear ratio of 0.479:1. Thus at a war emergency power using 3,000 crankshaft revolutions, the propeller is running at a speed of only 1,437 revolutions per minute. This stock reduction gear ratio is also adequate for moderate overspeed engine operation (3,100 to 3,300 rpm) and was the norm at Cleveland during the late 1940s as well as the early years at Reno. In later years, *Merlins* were run at higher speeds (3,400–3,600 rpm) and a lower gear ratio had to be employed. Engine builders resorted to installing transport reduction gears in the nose case (providing a ratio of 0.420:1) to maintain propeller tip speeds below sonic velocity. More recent *Merlins* have been run at speeds as high as 3,800 to 4,000 revolutions per minute. To facilitate these speeds, custom reduction gears are used with ratios slightly under 0.400:1. Selecting the correct gear ratio for a specific race is a complex calculation contingent upon such considerations as desired engine speed, anticipated air temperature and barometric pressure as well as the propeller diameter. This degree of sophistication, for example, was employed in the setup of the racing *Merlin* for DAGO RED. Such attention to detail led DAGO RED to victory in the 1982 Reno Championship Gold Race.

If previous *Mustang* victories at Reno were the result of superb technical effort, performance of the *Merlin*-powered "Strega" during the record-setting 1987 Gold Championship Race can only be described as flawless. Indeed, Dwight Thorn's engine setup using dash 9 gears with the supercharger operating in low blower coupled with Allison connecting rods may represent the ultimate in racing *Merlins*. Employing the stronger Allison rods no doubt contributed to the astounding durability of this *Merlin* throughout the race week at Reno '87. Under the meticulous supervision of crew chief Bill Kerchenfaut, Strega's *Merlin* performed infallibly at a reported 135 inches manifold pressure and engine speeds in excess of 3,000 revolutions.

Engine Cooling—Racing *Merlins* release tremendous quantities of heat due to combustion. If stock radiators are retained on racing *Mustangs*, cooling augmentation is imperative.

Engine rebuilder Mike Nixon specializes in *Merlins* at his "Vintage V-12s" shop. In the foreground is a *Merlin* with the heads and banks removed. (Photo credit: Birch Matthews)

TABLE 5 — ENGINE COOLING OPTIONS FOR HIGH SPEED AIRCRAFT USING LIQUID-COOLED AIRCRAFT ENGINES

Method	Configuration	Remarks
Surface Radiators	Airframe surface or skin incorporates coolant passages. High-velocity low-temperature air passing over the skin removes heat by convection from the oil and engine coolant pumped through their respective passageways.	This technique used on various high-speed and racing aircraft during the 1920s and 1930s. Method required large surface areas and reduces airfoil efficiency when wing surface is used. Coolant passages were copper because of its high thermal conductivity; however, this imposed a weight penalty.
Fin and Tube Radiators	Compact fin-and-tube radiators transfer heat from the hot liquid in the tubes by conduction through integral fins exposed to the airstream. Heat is removed from the fins by convection to the air moving through the radiator core. Pressurized cooling systems are used to raise the boiling point of the coolant allowing smaller radiators with reduced aerodynamic drag.	Compact efficient aircraft radiators are suitable for ducted air scoops such as used on the P-51 Mustang. Air entering the scoop is slowed in a diverging section ahead of the radiator core with a corresponding increase in static pressure. Heat from the engine coolant (oil, etc.) is transferred to the airstream simultaneously elevating the air temperature. High temperature air is then accelerated in a converging section of the duct to a small exit area. Passing the heated air through this nozzle imparts a measurable thrust. This partially offsets drag induced by the presence of the duct and radiator core.
Coolant Boiling	Engine coolant is allowed to elevate in temperature to just below boiling and then "flashed" to steam upon leaving the engine. The vapor is routed through an air-cooled condenser to return it to the liquid state. Oil cooling has been accomplished by immersion of the radiator in water-alcohol bath. Heat is removed from the high temperature oil into the bath which boils at 150 degrees F. Vapor is simply vented overboard. Oil temperature is thus maintained at about 212 degrees F.	The Rolls-Royce Goshawk utilized this cooling principle in a limited number of service aircraft but not without reliability problems. The Messerschmitt BE-209V1 powered by a highly modified Daimler-Benz DR-601A engine used a boiling system to establish the world speed record in 1939. This technique was used by Darryl Greenamyer in his world record-setting FBF-2 Bearcat and also by Mike Carrol in his ill-fated Cobra III project. High performance flight time is obviously limited by the amount of water mixture carried in the boiler.
Spray Bar Systems	Conventional or stock radiators are equipped with water spray nozzles located in front of the heat exchangers. Atomized water droplets are sprayed on the radiator fins to remove additional heat when the engine is operated such as to produce thermal loads above the radiator design maximum.	Spray bar systems are commonly used on all competitive unlimited racers of the current era. For radial engines, spray systems are used on the oil coolers. Liquid-cooled Merlins employ water spray bars for the engine coolant, oil and supercharger aftercooler radiators. About 100 to 110 gallons of spray bar water is carried during a Reno championship race. At maximum power, spray bar water will last about 12 minutes.

*Merlin*s operating at high manifold pressures and engine revolutions release correspondingly more heat than their stock cousins. Waste heat introduced into the engine coolant and oil must be dissipated or redline temperatures will be exceeded with accompanying catastrophic results. Methods of heat dissipation are outlined in Table 5. Each approach is valid; however, the method selected must accommodate specific high-speed flight requirements. Pylon racing at Reno demands maximum cooling for perhaps 12 minutes at most. Under these conditions, spray bar cooling augmentation has proved the optimum choice.

Cooling radiators in stock *Merlin*-powered *Mustang*s are sized to dissipate waste heat generated at war emergency power. At higher power settings for racing additional waste heat must be removed. For example, the theoretical chemical energy released at war emergency power of about 1,500 horsepower is approximately 18 million Btu's per hour (300,000 Btu's per minute). A racing *Merlin* generating twice as much power results in a heat release approaching 36 million Btu's per hour (600,000 Btu's per minute).* This additional 18 million Btu's per hour (actually somewhat less when various thermal efficiencies are considered) could be removed by doubling the radiator size and capacity. In at least one instance, this approach was utilized. The 1946 Thompson Trophy-winning Bell P-39Q *Cobra* II added a second oil radiator located in a duct beneath the wing. This solved a high temperature oil frothing problem but added airframe weight and drag.

The optimum solution for Reno pylon racing is spray bar cooling. The amount of heat required to vaporize water is approximately 1,000 Btu's per pound. Thus by spraying water droplets on heated radiator fins additional heat is removed as the water is evaporated.

The first spray bar cooling system employed on a *Mustang* occurred at Reno in 1964. The aircraft was Chuck Lyford's beautiful white P-51D sponsored by the Bardahl Company. This aircraft was powered by a Dwight Thorn-built V-1650-9 *Merlin*, which at high power output, required additional cooling to cope with increased heat rejection to the engine coolant and lubricating oil.

At Reno, championship class *Mustang*s consume seven or more gallons of water per minute through the spray bar nozzles.* This rate of spray bar flow allows the pilot to race with the coolant door closed to minimize aerodynamic drag. To achieve this drag reduction even relatively stock racing *Mustang*s usually employ spray bar systems though water throughput is reduced to about two and one-half gallons per minute.

Because the laws of physics are always with us, utilization of a spray bar system to remove excess heat is not without penalty. The timed portion of the championship race lasts about 10 minutes. Additional race power is required to accelerate down the "chute" plus the initial lap around the course to the home pylon when timing begins, means that about 12 minutes' worth of spray bar water is required. For this overall duration, typically 80 to 90 gallons of water may be consumed. By using a thin bladder in place of one wing 92 gallon fuel cell, about 110 gallons of water can be carried for the spray bar system. This imposes a weight penalty of over 900 pounds at takeoff. As with fuel, the water is consumed during the race so airframe gross weight is continually reduced.

*A moderate sized home is warmed by a gas-fired furnace with an input rating of around 150,000 Btu's per hour. Thermal energy released during a Reno championship race in one *Merlin* is sufficient to heat this home for almost six days during the winter season.

**Stilleto* requires up to nine gallons of spray bar water per minute. Race consumption may therefore be as much as 108 gallons for this aircraft often making the final lap interesting if not a bit precarious.

Conversely, the power-to-weight ratio continually improves as the race progresses—a decided advantage over other potential heat-removal schemes. Any discussion of spray bar cooling is incomplete without acknowledging Lockheed engineer Pete Law who has perfected this cooling technique. Most Reno racers utilize one of his systems.

In a similar vein, recognition is due builders of racing *Merlin* engines. Names such as Jack Hovey, Mike Nixon, John Sandberg, Dwight Thorn, and the late Dave Zueschel are relatively unknown to most air racing stalwarts. Intimately known within the racing fraternity, each has toiled to perfect the ultimate *Merlin*. It is also worth noting that all have built upon the original *Merlin* engine design, a truly elegant solution to the requirement for a liquid-cooled V-12 powerplant.

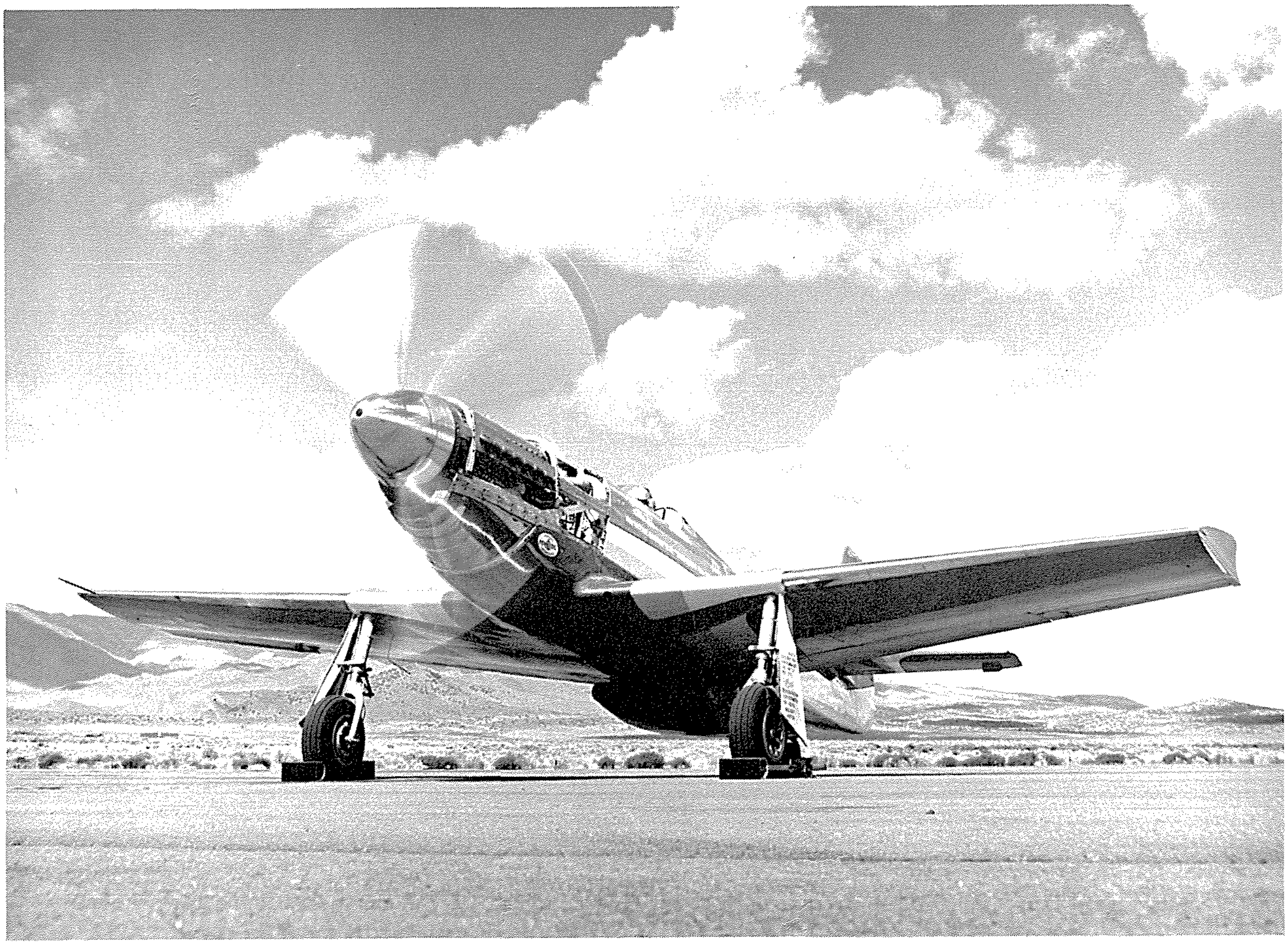
***Mustang* Powerplant Addendum**—Emphasis in this narrative has justly concentrated on Rolls-Royce *Merlins* and license-built Packard engines. As a historical footnote, *Mustangs* have raced with other engines. During the late 1940s, at least two *Mustangs* flew with Allison engines. In 1981, history was repeated when Ed Maloney (Planes of Fame Air Museum) entered a P-51A powered by an Allison V-1750-81 engine.

Conceived by N.H. Gilman, manager of the Allison Engineering Company located in Indianapolis, Indiana, the original engine was designed to produce 750 horsepower some two years before work on the *Merlin* began.* Through the trials of America's Depression years, Allison's early support was ultimately furnished by the U.S. Navy for their airship program. Belatedly, the Air Corps accepted the liquid-cooled Allison engine for evolving pursuit aircraft, notably Lockheed's P-38 *Lightning*, Bell's P-39 *Airacobra* and the P-40 *Warhawk* produced by Curtiss. North American Aviation also designed their *Mustang* prototype and early production aircraft around the Allison engine. The dash 81 Allison developed 1,330 horsepower but lacked adequate supercharging to bring the *Mustang* to its ultimate military potential. Although generally considered structurally stronger than a *Merlin*, the Allison never matched its counterpart in racing. It forever lacked a comparable supercharger.

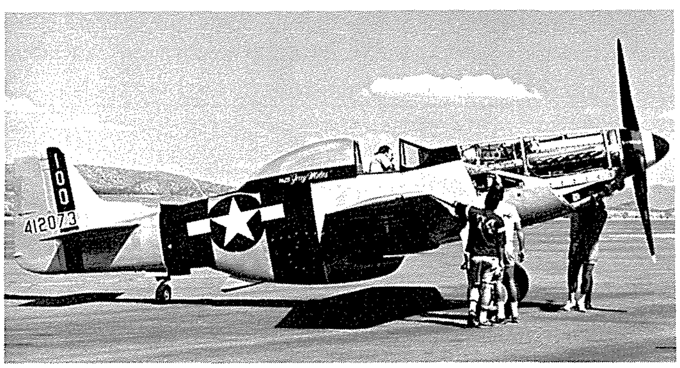
Perhaps the ultimate *Mustang* powerplant combination involved a modified Rolls-Royce *Griffon*. Design of the *Griffon* began in 1939. Equal in volume to the Rolls-Royce R engine, the *Griffon* has a displacement of 2,239 cubic inches, a 36 percent increase over the *Merlin*. Rolls-Royce very cleverly designed the *Griffon* to fit into *Merlin*-powered

*When founder James A. Allison died in 1928, his company was sold to General Motors Corporation. The organization remains a division of GM to this date.

A common scene in the Reno Unlimited Class pit area. Bill Destefani's highly modified P-51D, *Strega*, undergoing an engine change during the 1983 Reno National Championship Air Races. Four years later, *Strega* would win the Reno event at record-setting speed. (Photo credit: B. Matthews)



Race number 4 on the ramp at Reno during an engine runup. This Unlimited Class champion was photographed with a shutter speed of 1/60th of a second to illustrate the propeller arc reflecting the rays of the sun.
(Birch Matthews photo)



Representative of relatively stock *Mustangs* raced at Reno is Race 38 running-up on the ramp at Stead Field. Flown by Fred Sebby, this racer carried a *Merlin* engine by Mike Nixon. (Photo credit: Birch Matthews)

airframes with minimal modification. Thus the "RB-51 Red Baron Mustang" crew was able to adapt the *Griffon* into a *Mustang* airframe. This *Griffon* was a composite engine consisting of a dash 57 engine turning counter-rotating propellers coupled with a dash 74 blower. The resulting combination was fed by a Pratt & Whitney R-2800 carburetor and water-injection regulator. This potent 3,400-horsepower engine was the creation of Randy Scoville and Dave Zuechel. The result was a powerplant which produced the present world's piston engine speed record of 499.018 miles per hour plus four championship race victories including the 1977 and 1978 Reno National Championship Races, a truly remarkable achievement. . . .

Appendix A — SUPERCHARGING THE MERLIN

Among various *Merlin* marks and Packard dash numbers one will find both single-stage and two-stage blowers or superchargers, terms which in this instance are synonymous. *Merlin* superchargers are driven by the engine crankshaft through a step-up gear drive. Whether single- or two-stage, the supercharger may be operated at either of two speeds called low blower and high blower, respectively.* In their original application, the two-stage blower was used to enhance high-altitude engine performance. Single-stage blowers served to increase engine power for specific low-altitude military missions.

The supercharger is an integral and all-important device in unlimited air racing. For it is this device which provides over-boosted manifold pressures applied to racing *Merlins*. Fundamentally, the centrifugal blower consists of a wheel or disc incorporating vanes extending over the radius of the disc. This is called a rotor. In turn, the rotor is enshrouded in a close-fitting housing or blower case. In a two-stage blower,

*The desirability of supercharging aircraft engines was recognized in the earliest days of powered flight, certainly prior to 1914. Centrifugal blower development profited greatly from steam turbine technology.

the second rotor is positioned in series with the first. A fuel-air mixture enters the center of the rotor, turns 90 degrees and flows radially outward between vanes. Because the rotor turns at very high speeds, a large centrifugal force is imparted to the fuel-air (charge) mixture. As the charge leaves the rotor passages it next flows through fixed diffuser vanes allowing the fluid to expand and decelerate trading velocity for pressure buildup. Properly designed blowers achieve efficiencies as high as 75 percent. It was mathematician Sir Stanley Hooker who refined the *Merlin* supercharger to reach this efficiency level.

As noted previously, supercharger rotors run at high speed. The two-stage *Merlin* dash 7 blower is typically used for Reno competition. At maximum race power settings a *Merlin* will turn 3,800 revolutions per minute. Step-up gears in low blower at this crankshaft speed drive the rotor at 22,000 revolutions per minute with corresponding rotor tip speeds of more than 1,100 feet each second.

Air processed by the blower undergoes compression heating, a decided detriment. As charge temperatures increase, weight density decreases and engine power diminishes. To counteract compression heating, the charge is passed through a heat exchanger called an aftercooler (also referred to as an intercooler) before entering the engine induction passageway. The aftercooler is liquid-cooled and sensible heat in the charge is transferred to the liquid. Depending upon outside air temperature, charge temperatures entering the induction system will vary between say 150 to perhaps 250 degrees F.

Manifold pressure is a function of engine speed because the supercharger is gear driven by the crankshaft. At constant engine speed, manifold pressure realized is dependent upon ambient air conditions of barometric pressure, temperature and moisture content (humidity). At Reno where the unlimited course is at an altitude of about 5,000 feet, standard altitude pressure is perhaps 13 to 14 percent less than that experienced at sea level. Standard atmospheric values are further modified by prevailing local weather. For instance, if a low-pressure weather front moves through the Reno area, the barometer will drop accordingly. In this situation, the supercharger is pumping from an ambient air pressure lower than standard and the resulting manifold pressure will be correspondingly reduced. In other words, the supercharger must work with whatever ambient pressure exists. At low barometric pressures, the loss in manifold pressure after supercharging can amount to as much as five percent relative to standard conditions.

The second weather parameter influencing manifold pressure delivered to the engine is air temperature. Weight density (pounds per cubic foot) of air varies directly with temperature. At high ambient temperatures, weight density decreases and less air mass is available for the engine to process. Similarly, charge cooling after supercharging is somewhat reduced when the ambient air stream is hot. In other words, the charge temperatures can never be reduced to a point below ambient air temperature even if the heat transfer process were 100 percent efficient, which it certainly is not.

Humidity also affects engine performance. High moisture content tends to reduce engine power output because chemical energy introduced into the cylinders is diluted. The converse is also true. Climatic conditions at Reno can vary dramatically during race week in September. Frequently, however, weather conditions approximate that of a semi-arid climate producing pleasantly warm days with low humidity. Under these conditions, the *Merlin* blower performs at near ideal capacity to the delight of race crews.

Much of the preceding discussion centers on race operations at Reno where the altitude of Stead Airfield is about 5,000 feet. Atmospheric conditions often found during the September races at Reno typically result in the following supercharger performance for a dash 7 operating in low blower:

Rev/Min	Manifold Press. In.-Hg	Horsepower Consumed
3400	100	620
3600	110	820
3800	120	1050

Thus for each 200 revolutions per minute increase in engine speed, an additional 10 inches of manifold pressure is realized. It is further obvious that high manifold pressure operation consumes a sizable fraction of the engine power output.

Manifold pressures greater than 120 inches have been obtained in *Merlin* racing engines but at lower altitudes. In 1985, Skip Holm reportedly achieved around 140 inches of manifold pressure at 4,000 revolutions flying STILLETO during the Bakersfield, California, air race. And Don Wittington ran PRECIOUS METAL at a sustained 4,000 revolutions during a 90-mile test in Florida after the 1979 International Air Races. Engine teardown following Wittington's flight revealed slight cracking around two or three valve keepers. The engine was otherwise apparently undamaged. Six years later at Bakersfield, Skip Holm was not so fortunate. At such speeds and manifold pressures, the *Merlin* is without doubt stresed to the limit.

It should be noted in passing that not all engine builders use an aftercooler downstream of the supercharger. In the absence of an aftercooler, charge air temperature is reduced by injection of greater quantities of antidetonant fluid (ADI). Evaporation of the ADI cools the charge as would the aftercooler. This approach eliminates the weight of an aftercooler and associated plumbing; however, it requires almost twice as much ADI flow, around 0.8 to 1.0 pounds per pound of fuel.

The charge mass flow, predominantly air, provided to the engine by the supercharger is measured in terms of pressure. In America, this is commonly referred to as manifold pressure and units of measure are inches of mercury. This relates to a column of mercury in a tube which rises to a height equal to that required to balance a corresponding column of air extending from the surface of the earth to the outermost reaches of our atmosphere. At sea level in a standard atmosphere, the mercury column will measure 29.92 inches. The British refer to manifold pressure as "boost" which is a measure of pressure above or below atmospheric pressure. This is called gage pressure and does not include atmosphere pressure. Units of measure for boost pressure are in pounds per square inch. Conversion from one system to the other is readily done. One pound of boost (pressure) plus 14.7 pounds per square inch multiplied by 2.04 is equivalent to manifold pressure in inches of mercury. Conversely, inches of mercury divided by 2.04 less 14.7 pounds per square inch gives boost pressure in pounds per square inch. A comparison of some common *Merlin* operating manifold pressures in both inches of mercury versus boost in pounds per square inch are tabled here:

M.P. In.-Hg	Boost Lb/In.²	
30	0	Atmos. pressure
61	15	Mil. power, dash 7
67	18	War emergency, dash 7
80	25	
100	34	)
110	39	)
120	44	) Race power settings
130	49	)
140	54	)

Some appreciation of pressure force magnitudes on engine components at high boost pressures is seen by considering what happens when 130 inches of mercury is reached during a race. Remembering that air inducted into the supercharger has an ambient pressure of approximately 30 inches of mercury, one realizes that the supercharger raises this pressure by a factor of 4.3 or about 64 pounds per square inch. When the charge enters each *Merlin* cylinder, it is further pressurized by the engine compression ratio of 6:1, reaching 383 pounds per square inch before ignition. Each *Merlin* piston has 22.89 square inches of surface area which when multiplied by 383 pounds per square inch of pressure equals 8,770 total pounds of force. In other words, at this point in time, some 4.4 tons of pressure force is reacting against the piston, cylinder walls and cylinder head. When the charge is ignited, expanding combustion gases result in even greater forces with pressures reaching some 1,100–1,200 pounds per square inch. From this simple exercise it is seen that loads imparted to the pistons, connecting rods and crankshaft are quite severe.

SOURCE MATERIAL AND CREDITS

Adaptation of the *Merlin* engine to a *Mustang* airframe has been well documented. The interested reader is invited to peruse "High Speed Flight" by Bill Sweetman (Jane's Publishing Company, Ltd., 1984) and "Mustang" by Robert Gruenhagen (Arco Publishing, Inc., revised 1976). The *Merlin* engine evolution is chronicled in two excellent books. One is "The Merlin in Perspective—The Combat Years," written by Alec Harvey-Bailey (Rolls-Royce Heritage Trust, 1983). The second is L.T.J. Setright's marvelous recounting of piston engine development over four decades entitled "The Power to Fly" (George Allen & Unwin Ltd., 1971). The author provides a comprehensive review of the Rolls-Royce R series, *Merlin* and *Griffon* engines as well as other world class engines. His recount of these engines is interspersed with typical understated humor only the British have mastered. The R series engines of 1929 and 1931 are further described in *Schneider Trophy Aircraft, 1913–1931,* by author Derek N. James (Putnam & Company Ltd., 1981).

The life and times of Sir Henry Royce were described in a paper presented before the prestigious Royal Aeronautical Society and reprinted in *The Royal Aeronautical Society Journal,* Vol. 60, No. 552, December 1956. This paper was the source of comments made by Major G.P. Bulman concerning the origins of the *Merlin* "private venture" status footnoted in the preceding test. Aspects of *Merlin* development as well as the R series engine, including personalities involved, make this paper particularly valuable. In his book, *Leader in the Skies* (Frederick Muller Ltd., 1981) author Michael Donne also presents a synopsis of the Rolls-Royce company history.

An article entitled "Development of the Rolls-Royce Merlin from 1939 to 1945" provides a great deal of insight with respect to wartime evolution of the *Merlin.* Originally delivered as a lecture by Mr. A.C. Lovesey of Rolls-Royce, his historical remarks were reprinted in *Aircraft Engineering,* July 1946 issue. A less detailed yet quite interesting writeup appeared in another British periodical of more recent vintage. "Merlin—the Wizard of the War" by Mike McCarthy (*Old Motor,* September 1981) emphasizes the *Merlin*'s heritage as well as the continual increase in power output achieved through Rolls-Royce development efforts.

Reference material on the evolution of the Rolls-Royce *Merlin* engine would be absolutely incomplete without mention of two other books: *Not Much of an Engineer,* by Sir Stanley Hooker (Airlife Publishing Ltd., 1984), and Air Commodore F.R. (Rod) Banks' *I Kept No Diary* (Airlife Publishing Ltd., revised 1983). The first source provided the quotation by Sir Stanley about the four strokes of a piston engine. His outstanding contribution to the theory and development of the *Merlin* supercharger is a milestone in engineering technology. Rod Banks was a world class expert in aviation fuels and it was he who concocted the mixtures used in the 1929 and 1931 Supermarine Schneider racers.

All of these texts describe to one degree or another the supercharger technology which made the *Merlin* such an outstanding engine. Dr. Sanford A. Moss was a U.S. pioneer in this technology and he chronicles supercharger development in his book, *Superchargers for Aviation* (National Aeronautics Council, Inc., 1941). For the more technically inclined, there are numerous textbooks devoted to the internal combustion engine. If only one is to be consulted, C.F. Taylor and E.S. Taylor wrote one of the finest in their book, *The Internal Combustion Engine* (International Textbook Co., 1948). Miscellaneous information on the *Merlin* and *Griffon* will be found in several other noteworthy references. These include the *Air Annual of the British Empire,* edited by C.G. Burge (Gale & Polden Ltd., the 1931–1932 and 1936–1937 editions). Three different editions of *Jane's All the World's Aircraft* (McGraw-Hill Book Company, Inc.) were consulted for technical information and statistics (1941, 1946 and 1950–1951 editions).

Although the Allison V1750-81 engine was a footnote in *Mustang* racing history, it was cited for completeness. The above editions of *Jane's* provided useful background information as did two historical narratives: *The Curtiss D-12 Aero Engine* (Smithsonian Institution Press, 1972), written by Hugo T. Byttenbier, and *My Years With General Motors* (Doubleday & Company, Inc., 1964) by Alfred P. Sloan, Jr.

Written source material for the postwar races in Cleveland, Ohio, is scarce with respect to engine modifications and operating parameters. The general trend in these matters, however, may be gleaned from a review of contemporary magazine articles and newspaper columns. These include two articles by Robert McLarren in "Automotive Industries," 15 September 1947, and 1 October 1948. Additional comments will be found in Robert Hull's *A Season of Eagles* (Robert Hull Books, 1984).

The basis of information compiled for *Mustang* racing powerplants during the late 1940s was partly derived from oral history recorded on audio tape. The first important piece of oral history to surface was a tape recording of a presentation made to a group of Chicago historians by General Wilson Newhall who raced at Cleveland after the war. The original recording was made in May of 1964 by John Andrews who had the foresight to record the late General Newhall's personal experiences. This valuable information would never have been available as source material except for the dogged determination of Chicagoan Tony Yusken who located the recording two decades later! His generosity in providing a copy of this tape is acknowledged. Air race enthusiast Oliver Aldrich graciously supplied two taped interviews with Charles Walling who raced at Cleveland for J.D. Reed. This information complemented that gleaned from the Wilson Newhall tape. Although documentation is typically scarce in the field of air racing history, Cleveland historian Al Chute generously provided a tabulation of unlimited aircraft entry form data from the 1949 race. The integral of all this source material, written and oral, is a reasonable picture of the state-of-the-art evolution in *Merlin* racing engines over four decades. Rounding out this compilation of data and information are two articles published in the *Journal* of the American Aviation Historical Society. Details of Anson Johnson's beautiful and highly modified 1949 *Mustang* are chronicled in "The Saga of N13Y" by Phillip C. O'Keefe (JAAHS Vol. 19, No. 4, Winter 1974). Oil frothing difficulties with "Tex" Johnston's 1946 Thompson Trophy winner are related in "Cobra" by Birch Matthews (JAAHS Vol. 8, No. 3, Fall 1963).

Like the late 1940s, written documentation about racing *Merlin*s in the current era is anything but plentiful. The few sources available were quite useful and again established trends. Jim Larsen's *Air Racers* (American Air Museum, Inc., 1971) is a valuable reference which among other things, describes the racing *Merlin* in Chuck Lyford's beautiful *Mustang,* race 8. Jim also detailed the buildup of Gunther Balz's 1972 Reno winner in "The Making of a Champion," published in *National Aeronautics Magazine,* Summer Issue, 1973. An interview with Lyle Shelton was also very helpful. Prolific author John Tegler described the *Griffon*-powered RB-51 *Red Baron* in a *Western Flyer* article (March 1975). David Esler reviewed this same championship air racer in the Febuary 1976 issue of *Air Progress.*

Contemporary *Merlin* racing powerplant practices were explained by several technical specialists involved in the sport. Taped interviews with Lockheed engineers Bruce Boland, Pete Law and Ray Poe were most valuable. In addition to their active participation in the modification of aircraft for unlimited racing, all share an interest in seeing this history recorded. Their patience in follow-up telephone interviews must also be acknowledged. Bruce Boland's wry sense of humor made the task that much more enjoyable. Pete Law's enthusiasm for the subject is accompanied by a rapid-fire delivery of facts and statistics. Without the comforting support of a tape recorder, the authors would probably have missed three-fourths of his valuable input. . . .

Descriptions of *Merlin* modifications in the present era were also recorded during interviews with Mike Nixon and the late Dave Zueschel. To Mike, the authors bestow a very special sense of appreciation. A patient man with a firm command of the technology and art needed to create high-powered *Merlin*s, Mike described the essentials of building an engine to withstand the rigors of Reno pylon racing. Making the interview more pleasurable was a tour through his Vintage V-12 engine rebuilding facility. And to technical specialist and air racing historian Roger Huntington, a verbal handshake for his insight, perspective and encouraging review comments. A final note of thanks is particularly due Shirley House who laboriously prepared and revised our manuscript.

To all of the past and present historians whose works provided source material for this effort, the authors are very grateful. We hope they will find satisfaction in the written narrative of their contributions. To all our unqualified appreciation.