CRYOGENICS

THE RACER'S EDGE

Extremely low-temperature treatments boost the performance and service life of critical components.

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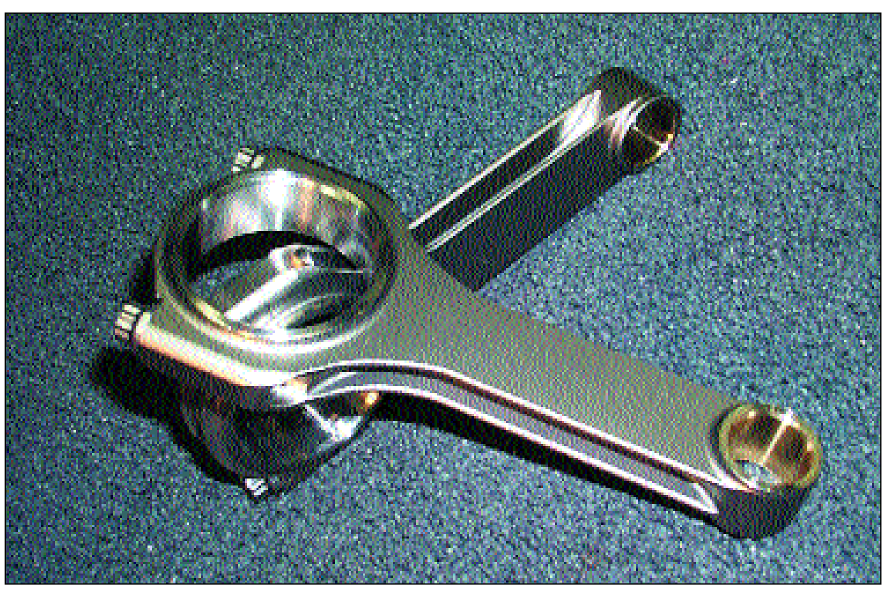
Racing pushes engine and drive train components to the absolute limits of their durability. Extending those limits means more speed, better safety, and more races won. For this reason cryogenic processing is becoming a necessary part of the manufacturing process for racing components. This racing experience will serve as an example to manufacturing industries — now similarly engaged in their own competition against manufacturing costs and waste, and the challenge to provide high quality products with superior performance.

Using extremely low temperatures to make permanent changes in metal and plastic components, cryogenic processing is not the typical -84°C (-120°F) cold treatment most heat treaters use. It essentially involves exposing materials to temperatures below -184°C (-300°F). If done correctly, it creates a permanent change to the material that alters many wear characteristics.

The concept of changing metal through the use of low temperatures is relatively new and not well understood. Yet it is certain that exposure to very low temperatures does make permanent changes in virtually all metals and to some plastics. Observed changes include:

- Increased resistance to abrasion
- Increased resistance to fatigue.
- Precipitation of very fine carbides in ferrous metals that contain carbide forming elements.
- Transformation of austenite to martensite in ferrous metals.
- Change in vibrational damping.
- Increased electrical conductivity.
- Anecdotal evidence of changes in heat transfer.
- Stabilization of metals to reduce warping under heat, stress, and vibration.

In practice, cryogenic processing affects the entire mass of the part. It is not a coating. This means that parts can be machined after treatment without losing the benefits of the process. Additionally, cryogenics apply to metals in general, not just ferrous metals. For many years, it was assumed the only change caused by extreme cold was the transformation



Connecting rods usually fail in fatigue. These lightweight, forged 300M steel connecting rods use cryogenic processing to resist the forces generated by an engine turning over 9000 rpm.

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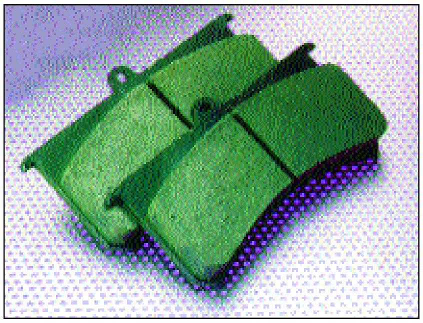

Fig. 1 — Cryogenically processing brake pads yields a service life 2 to 3× that of untreated pads. Race drivers also report better braking action and feel.

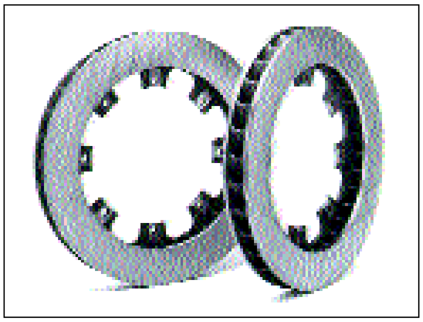

Fig. 2 — Racing technology adapted for street use. The use of cryogenic processing to triple the life of brake rotors is now spreading to fleet vehicles such as police cars and taxi cabs.

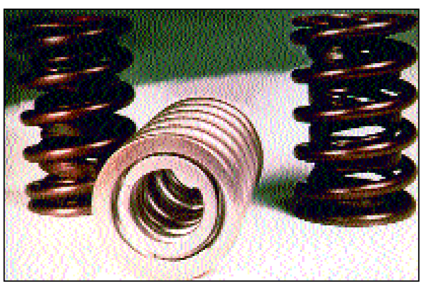

Fig. 3 — Valve springs show dramatic improvement in fatigue life, lose less preload, and show a smaller loss of spring constant when cryogenically processed. Vibrational characteristics are also changed.

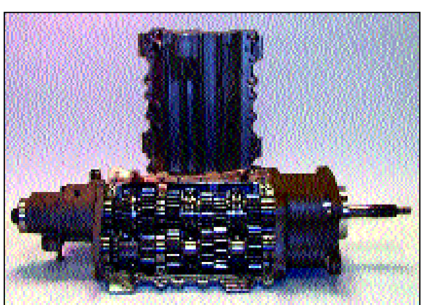

Fig. 4 — Jerico Performance Products is one of the racing component manufacturers that has recognized the value of cryogenic processing in extending component life. All gears, shafts, dogs made by Jerico are now cryogenically treated. In the year 2000, two thirds of the Winston Cup (NASCAR's premier series) race winners used transmissions made by Jerico.

of retained austenite to martensite in steel and iron. Because of this, many misinformed engineers still believe that cryogenic processing is "just a fix for bad heat treat." It is now known that cryogenic processing has a definite affect on copper, titanium, carbide, silver, brass, bronze, aluminum, both austenitic and martensitic stainless steel, mild steel, and others. It is also known that plastics such as nylon and phenolics show property changes.

Racing applications

Cryogenic processing is currently in use in every form of racing imaginable. It is used in virtually every class of NASCAR racing, IRL, CART, NHRA, IHRA, SCCA, IMSA, and ARCA, not to mention tractor pulls, go-karts, motorcycles, boats, and even lawn mower racing. Controlled Thermal Processing (CTP) has even done a fair number of axles for soap box derby cars. Over half of the cars competing at any given NASCAR Winston Cup race run parts that are cryogenically treated by CTP alone. Cryogenic processing can have a positive affect on virtually every engine, transmission, and drive line part, as well as many chassis parts.

Are there definitive tests and data on racing and cryogenic processing that we can point you to? Not yet. Racers do most of their testing on the race track or on the dynamometer. These are not controlled experiments in the classical sense, and in most cases they do not allow the results to be published because of the risk of losing competitive advantages. We do know that the use of cryogenic processing is on the upswing. Its use by manufacturers of racing components has been growing sharply. We also know that very experienced racing experts have examined the effects of cryogenic processing and have been very impressed.

Increasing the durability of components in the vehicles is the main reason for using cryogenic processing. Racing continually presents the engineer with the challenge of designing engine and chassis components that will survive long enough to win a race, but will not have any excess weight as a consequence. Put in too much mass, and a car will be slow and handle poorly. Make components too light, and they will not survive the race. There is always this delicate balance: weight versus reliability. The great thing about cryogenic processing is that it allows an increase in durability without an increase in weight or major modifications to component design. In addition, the use of cryogenic processing has helped some racing teams reduce costs, enabling some expensive parts to survive the stresses of racing for use in subsequent races.

Performance advantages

Cryogenic processing has become an integral part of the production process for many racing components. Many top racing teams have the process done if the manufacturer does not provide it. They do so because cryogenic processing has proven its worth time and again under extremely competitive conditions. Racers are generally people in a big hurry and would not take the time for cryogenic processing if there was no advantage to it. Applications that benefit from cryogenic treatment probably number more than anyone expects.

Brakes and Clutches. Brakes of a racing car take a real beating. It is not unusual for a racing vehicle to finish a race with the brakes totally worn out. This is especially true during road races and endurance racing, where brake rotors can get so hot they glow visibly at night. Cryogenic processing can be applied to both rotors and pads. The net result is two to three times the life of untreated components even under severe racing conditions. As a side benefit, the rotors are less prone to crack or warp. It is interesting that drivers report better braking action and feel. Some drivers are so sold on the concept that they have their street vehicle equipped with treated brakes.

Clutches are a form of brake, and the results are very similar. Drag racers have been doing some work on clutch plates to measure the coefficient of friction in highly instrumented cars. They find that treated clutch facings will develop a higher coefficient of friction but exhibit significantly less wear.

As an offshoot of racing development, cryogenically treated rotors and pads are making their way into fleet operations on the road. The U. S. Postal Service specifies cryogenic processing for their rotors and is experiencing up to three times as many miles as they were getting on the unprocessed rotors. Similarly, many police fleets are starting to adopt treated rotors and pads. They, too, are experiencing large maintenance savings on both parts and labor. What is metallurgically interesting is that the brakes are a gray cast iron that has a pearlitic structure. This rules out the austenite to martensite transformation as the mechanism for increased life.

Springs fail in one of two modes. They either break or their spring constant starts to decline. Either way, it can have catastrophic effects on the performance of the vehicle. Most valve springs are made of specially made chrome silicon steel. The automotive valve spring is a fatigue failure waiting to happen. It typically can lose up to one third of its spring constant during a long race. In some forms of racing, it is just hoped that the valve springs will last through the race. Some drag racers routinely change the valve springs before every run down the drag strip to ensure consistent performance. Typically valve springs exhibit a longer life after cryogenic processing. How much depends on the type of racing, the type of spring, the manufacturing lot of the spring and the criterion for a failure.

Cryogenic processing of springs will usually triple the life before fatigue failure occurs, and it will reduce the amount of spring constant lost from 20 to 30% down to about 7%. This makes it easier to set up the engine, as there is not such a wide variation in the spring performance. It is difficult to determine absolute spring life increases, because the racers typically discard them long before they break. We do know one drag racer who used to change springs after each run: he now makes seven runs before changes. There is a caveat here. Occasionally we come across groups of springs that will not respond to cryogenics. Analysis of these springs usually discloses large inclusions in the wire, which become stress concentrators, causing failures at these locations.

A further advantage for cryogenic processing of springs is that the process seems to eliminate or reduce harmonic vibrations. If you have ever seen a high-speed movie of a valve spring at high engine rpm, you will notice that the spring does not simply move up and down. It does a very complex hula dance because of the harmonic vibrations. Racers typically have to design the spring and valve trains so that harmonics do not interfere with the valve action.

Not unexpectedly, chassis springs are also affected by cryogenic processing. Chassis springs lose their spring constant during a race. This can cause the chassis to lose its cornering ability, which drastically slows the car. Loss of spring constant also alters the height or road clearance of the vehicle. The vehicle height is critical at high speeds because it has a big affect on the aerodynamics of the car, and hence on the handling and the top speed of the car.

Other ramifications of springs sagging are evident. Watch the pit crew after a Winston Cup race as the car is pushed up on to a platform for inspection. If the springs have settled too much, the car may be disqualified. So the pit crew will often be lifting on the chassis as they roll it along to set it up a little higher. When they get the car to the measuring surface, they gently let it down so it does not bounce and settle farther than necessary. You have to know the tricks if you don't want to lose.

The chassis itself is basically a very large, complex spring, having numerous welds and using not very precise tubing. The metals used here vary, depending on the type of racing. NASCAR frames are made from 1020 steel; other forms of racing use 4140 steel. Of course, other high strength, lightweight materials are also used.

As the chassis experiences vibration during the race, residual stresses in the welds and the tubing can start to relieve. This causes the chassis to change shape during the race, affecting the handling of the vehicle and therefore its speed. We are now working with several teams to do a heat stress relief on the chassis followed by a cryogenic treatment.

Gears, shafts, and assemblies. A study for the U. S. Army Aviation and Missile Command, by the Illinois Institute of Technology Research Institute concluded that cryogenic processing of carburized 9310 steel increased the gear contact fatigue life by 100%, and the ability of the gear to handle load by 10% over the same material that had undergone a -84°C(-120°F) cold treatment per military specification. They also found that the conversion of retained austenite is only part of the effect on the gear. Most racing gears are 9310 carburized steel, although 8620 is also used. It is interesting to note that there is an experimental gear material under test that specifies cryogenic processing as part of its heat treat.

One major racing transmission maker, after inspecting numerous gearboxes after races, has ascertained that cryogenic processing cuts the gear wear dramatically. This also holds true for road racers of Porsches and BMW's and other SCCA race cars who are now getting about three times the life on their gear boxes. The major problem all of these racers see is wear on the pitch line of the gear. Breakage is sometimes a problem, but that can usually be traced to driver error, bad heat treatment, or inferior material. Jerico Performance Products, a well known producer of racing transmissions, supplies gearboxes to over 50% of the racers in Winston Cup, and to many other racers. The company currently has all of its gears and shafts cryogenically processed.

Cryogenic processing also increases the life of other heavily loaded gears. We see a doubling of the life of ring and pinion gears in differentials, even under such severe usage as tractor pulls. Quick-change gears also show dramatic increases in life. Axle shafts, universal joints, and constant velocity joints all show dramatic increases in durability. As the racing of front wheel drive cars becomes more popular, we begin to see more and more constant velocity joints being processed, as this is one of the weak points of the drive line. Axles are treated to stave off fatigue failures in the splines.

Fig. 5 — All connecting rods made by Dyer's Top Rods are cryogenically processed. Dyer's has modified its heat treating to take full advantage of the benefits of cryogenic processing.

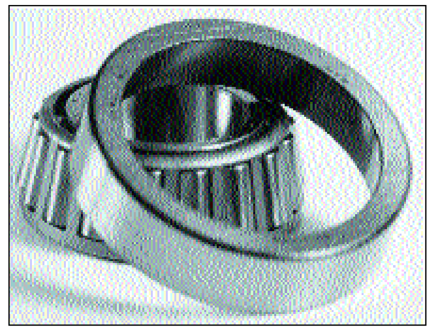

Fig. 6 — Cryogenic processing of ball and roller bearings increases their resistance to contact fatigue and increases life.

Engines respond

Virtually every part of an engine will respond to cryogenic processing, with all components exhibiting life increases. Several component manufacturers are starting to take advantage of this and are treating their racing components as part of their production. Some of the main applications are:

• *Connecting rods* usually fail in fatigue. This occurs because of the high "g" loading of the piston and pin. Winston Cup engines currently run around 9300 rpm. They have a stroke of around 86mm (3.375 in.) Pistons and pins typically have a mass of around 650 grams (23 oz.). Given these figures, it can be calculated that the upward force the piston and piston pin exerts on the connecting rod during the exhaust stroke is over 4800 g's. Although this calculation ignores the weight of the small end of the connecting rod, it can be seen that there is a repeated stress on the rod, which has a cross sectional area of under 230 mm^2 (0.35 $in.^2$). Cryogenic processing increases the fatigue life of connecting rods considerably. Dyer's Top Rods in Forrest, IL, claims that they would not release a rod from their shop without cryogenic processing. We process steel, titanium and aluminum rods. The steel rods are generally AISI 4340 or 300M steel, aluminum rods are usually 7075 T6.

• *Cylinder heads.* Both aluminum and cast iron heads usually fail by cracking, which results from both thermal cyclic fatigue and the flexing of the head under combustion pressures. Further, the heads are often subjected to the extreme pressures created when the fuel mixture detonates. All these pressures can cause the head to flex so much that it is not unusual to find debris such as piston coatings under the heat gasket, blown there during a combustion stroke.

Several Winston Cup teams have concluded that 356 T6 aluminum heads yield about double the life after cryogenic processing. Other racers have the heads (both aluminum and cast iron) treated as a matter of routine. Of course, treating the heads increases the life of valve seats and valve guides. It is interesting to note that the heads can be treated with the valve guides and seats installed.

• *Camshafts and lifters.* Roller lifters usually fail by breaking, some of which is just poor design with sharp edges and stress risers all over. Even so, one customer reports that he gets about five runs down the drag strip unless he cryogenically processes his lifters. After cryogenic processing, he typically gets over 100 runs.

Winston Cup rules specify solid lifters. These cars are turning around 9300 rpm, so valve spring pressures have to be very high to slam the valve shut. The current practice is to create a cam profile that will actually loft the lifter. The lifter is thrown up in the air, forcing the valve to open very fast and then the spring slams the lifter down back against the cam. This creates extreme wear, but it gets the valve wide open as quickly as possible and leaves it wide open to the last possible microsecond.

The lifters start with a slightly convex surface and wear into a concave configuration. Typically, they are cast iron and heat treated to the mid 50's HRC. In use, any wear increases the valve lash and delays valve lift, creating a loss of power. It also leaves a lot of wear particles in the oil. It can take up to three sets of lifters to get an engine through dyno testing and the race due to the extreme wear caused by these radical cam profiles and high spring pressures. Cryogenic processing reduces this wear by about half.

Camshaft wear is also a problem. Camshafts are generally carburized 8620 steel, but typical Winston Cup camshafts are 8620, with a layer of stellite welded or spray coated onto the lobes to help reduce wear. The stellite has a hardness of about 52 HRC. It wears and chips badly during a race, changing the valve lash and also the valve timing. In other forms of racing, camshaft wear is not as drastic, but still a definite problem, especially for racers who cannot afford a tear down after each race. Cryogenic processing has proven a boon to these racers because it reduces wear and therefore reduces camshaft replacement costs.

• *Bearings.* At least one racing bearing manufacturer cryogenically treats babbited bearings as part of their production process. They found it increased the life of the bearings and also of the steel backing, which tended to fail in fatigue. It is interesting that cryogenic processing has an effect on the babbit metal of the bearings. Similarly, bronze bushings used on wrist pins also wear considerably less when treated.

Many racers are processing ball bearings and roller bearings (typically 52100 steel) because they get a three to five fold increase in life. Rod ends used in steering and suspension systems get the same treatment and performance gains.

Cylinders, pistons and rings

Cryogenic processing of piston rings and cylinder walls has been shown to reduce wear substantially. One go kart racing customer claimed that he got a five fold increase in engine life before he had to freshen the engine. Better ring seal was born out in pressure readings on a dynamometer. Apparently, this happens because the parts machine and hone better after treatment as a consequence of a more uniform hardness distribution over the surface of the part. (This fellow was a national champion, so he must know his business.) CTP has done tests that show a significant reduction in the standard deviation of hardness readings taken before and after cryogenic processing. In some cases, the standard deviation is one-third of what it was before the process.

Processed piston rings typically wear both less and more evenly than untreated rings. More tribologically compatible with the cylinder walls, they tend to flutter less due to the vibrational damping the process imparts into the material and due to the more even hardness of both the rings and the cylinder walls. All these factors combine to give better ring sealing, and therefore more power.

Cryogenic processing of engine blocks also stabilizes the blocks and reduces warping and distortion due to vibration and heat during use. The same is true for pistons. Several engine builders, who specify the process, have taken careful measurements of pistons before and after use, finding that cryogenically processed pistons distort less under use.

Cryogenics plays a vital role in a process developed by CTP to induction harden the bores of cast iron blocks. This process reduces friction and wear. Here, initial reports indicate substantial horsepower gains from this process.

Crankshafts benefit greatly from cryogenics. Several of the most respected names in the crankshaft business use cryogenics as a part of their thermal treatment. Cryogenic processing greatly decreases wear on crankshaft journals and stabilizes the crankshaft. We have treated everything from stock cranks through special racing nodular iron cranks and racing cranks made of 4340 steel.

Virtually all parts that are subject to stress or abrasion can benefit from cryogenic processing. Even head gaskets benefit because the armor around the combustion chamber is subject to both thermal cyclic fatigue and to flexing fatigue.

Keys to the process

Success of cryogenic processing is critically dependent on the equipment in which the processing is done. The quality and function of the machines available varies from very poor to excellent. So does the ability of cryoprocessor manufacturers to support their machines with technical and processing advice. (More details on the equipment will appear in an upcoming *HTP* article.)

Cryogenic processing used to be fairly simple. Bring the part down to -184°C (-300°F) typically over an eight hour period. Hold the part at this temperature for eight to twenty hours, and bring it back to ambient temperature over a 15 h period, followed by tempering at a 149°C (300°F). This general formula can be used to good effect for many components, especially when all the previous thermal treatment specs are not known. As they say, though, the devil is in the details. The actual practice is harder than it looks. There are several large companies that have spent a lot of time trying to develop the process unsuccessfully. In fact, the idea that almost anyone can buy a cryogenic processing machine and set up a viable, reliable business is absurd. Metallurgical knowledge is not only helpful, but it is a requirement to achieve effective processing

The optimum process for any given part varies according to the metallurgy and the failure modes of the piece. Although "standard" processes will greatly improve components that are sent to us for processing, better results are achieved when the cryogenic process is part of an optimum package of material selection, production methods, heat treat and cryogenic processing. We even spend time analyzing component failures to allow us to optimize all factors in the thermal treatment of the part. This approach yields excellent results, especially for companies that do not have their own metallurgical staff.

Cryogenic processing is destined to become part of the standard production process as opposed to being an add-on process as it now exists. CTP selected Midwest Thermal Vac Inc., Kenosha, Wisc. for their unflagging attention to customers' needs and their quest for doing things right. MTV's president, Frederick Otto states, "It is becoming more and more obvious that cryogenic processing is a necessary and integral part of the thermal treatment of a quality component."

By helping customers set up realistic standards and specifications, we have allowed them to develop sophisticated metallurgical standards to ensure the metallurgical performance of their product. According to Roger Friedman of Dyer's Top Rods, "Integrating cryogenic processing with our materials selection, heat treat, and manufacturing methods has allowed us to make connecting rods that are both light and have a long service life under extreme racing conditions. The result? At the Eldora Million race, where there was a one million dollar prize for the winner, seven out of the first ten finishers used our rods, including the winner."

The use of cryogenic processing is now starting to extend into the production processes of companies. Racing component manufacturers are beginning to treat their tooling and their cutting tools. This is reducing their tooling costs considerably. One firearms manufacturer currently saves over $3,000,000 annually by treating its tooling.

The cryo future

More research into cryogenic processing is a certainty. When Illinois Institute of Technology created it's Thermal Processing Technology Center in conjunction with the National Science Foundation earlier this year, it purposely used the term "Thermal Processing" in the name because elevated temperatures are no longer the only means of thermal processing. One of the first proposed projects for this center is to study cryogenic processing to determine what factors cryogenic processing changed in metals. There is current interest in the use of the process on H13 steels.

Los Alamos National Laboratory, too, is very interested in doing more work on the subject. Their testing revealed that there were interesting things happening with steels that were cryogenically processed. They are eager to find industrial partners to help fund the research to delve into the process even further. **HTP**

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Car Racing Organizations

NASCAR, National Association of Stock Car Racers. This is the organizing body for "stock" cars. From the first race on the beach at Daytona in 1948, to last season's door-to-door thriller at Atlanta between Dale Earnhardt and Bobby Labonte. NASCAR has provided 52 years of motorsports racing. **www.nascar.com**

IRL, Indy Racing League. This is the organization responsible for the Indianapolis 500 and similar races. Indy cars are Open-wheel, single-seat cars, open-cockpit and ground-effect underbody; outboard wings front and rear.**www.indyracingleague.com**

CART, Championship Auto Racing Teams. Open wheel racing in North America and around the world in 21 events. **www.cart.com**

NHRA, National Hot Rod Association. Drag racing. Now in its fifth decade, the NHRA is the world's largest motorsports sanctioning body with more than 85,000 members, 144 member tracks, 32,000 licensed competitors, and nearly 4,000 member-track events. **www.nhra.com**

IHRA, Independent Hot Rod Association. Over 30 years of drag racing make the International Hot Rod Association a pioneer and trendsetter in the motorsports industry. Headquartered in Norwalk, Ohio, IHRA sanctions professional, sportsman, and bracket racing competitions for drivers at all levels. **www.ihra.com**

SCCA, Sports Car Club of America. Sports cars of all descriptions. The Sports Car Club of America is a 55,000-member nonprofit organization featuring the most active membership participation organization in motor sports today, with over 2,000 amateur and professional motor sports events each year. **www.scca.org**

IMSA, International Motor Sports Association. Racing of Sports cars in the LeMans series and others. www.professionalsportscar.com

ARCA, Automobile Racing Club of America. The Automobile Racing Club of America (ARCA) was founded in 1953 in Toledo Ohio as a Midwest-based stock car auto racing sanctioning body. **www.arcaracing.com**

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