

# Four on the floor

The traditional-style four speed has seen significant development for the COT



The COT rules call for the use of a “standard production design” gearbox, which has to be an approved model from one of eight current suppliers (Andrews, C&R, Emco, Jasper, Jerico, Tex, G-Force and Mid Valley). So far NASCAR has only approved gearboxes that follow the pattern of the Borg & Warner T-10, a four-speed plus reverse unit with an H-pattern shift first used in a passenger car application in 1957 by GM. Ford and others followed suit as it was proven rugged and dependable and in 1974 Borg & Warner introduced the updated ST-10. The rights to this design were subsequently acquired by Richmond Performance Products of Liberty, South Carolina, which still manufactures it as an aftermarket product.

The ST-10 is the gearbox used in United Speed Alliance Racing (USAR) stock car racing (Hooters Cup). Unlike current NASCAR gearboxes it has synchromesh and helical-cut gears. C&R South buys ST-10s from Richmond to modify for USAR competition, gun drilling the main shaft, lightening the gears, applying surface finishing and so forth. Some companies offer a magnesium replacement tail housing that is stronger and lighter than the stock aluminum production.

The currently approved NASCAR gearboxes retain the general layout of the ST-10 (see sidebar: ST-10) and are mandated to have an H-pattern shift. The rules state that top gear must be direct drive with none of the other three ratios providing an overdrive, so that NASCAR can impose its final drive ‘Gear Rule’. When top is selected the rules further insist that the drop gears continue to power the countershaft and thus all three lower ratios have to freewheel on the main shaft, in spite of the implicit frictional penalty. Reverse gear has likewise to be constantly powered. Nevertheless, C&R South has been able to develop a Cup gearbox with an efficiency of more than 98.8% when running in top. It helps that straight cut gears are permitted with non-synchromesh dog selection. On top of that has come a sophistication of detail design rivaling that of Formula One.

C&R South is based in Mooresville, North Carolina under the technical direction of Jeff ‘Fuzzy’ Horton. In October 2007 Horton was generous enough to take us through in detail the technology of his company’s Cup gearboxes.

“We added a support bearing between second and third gears to both the main and the countershaft”

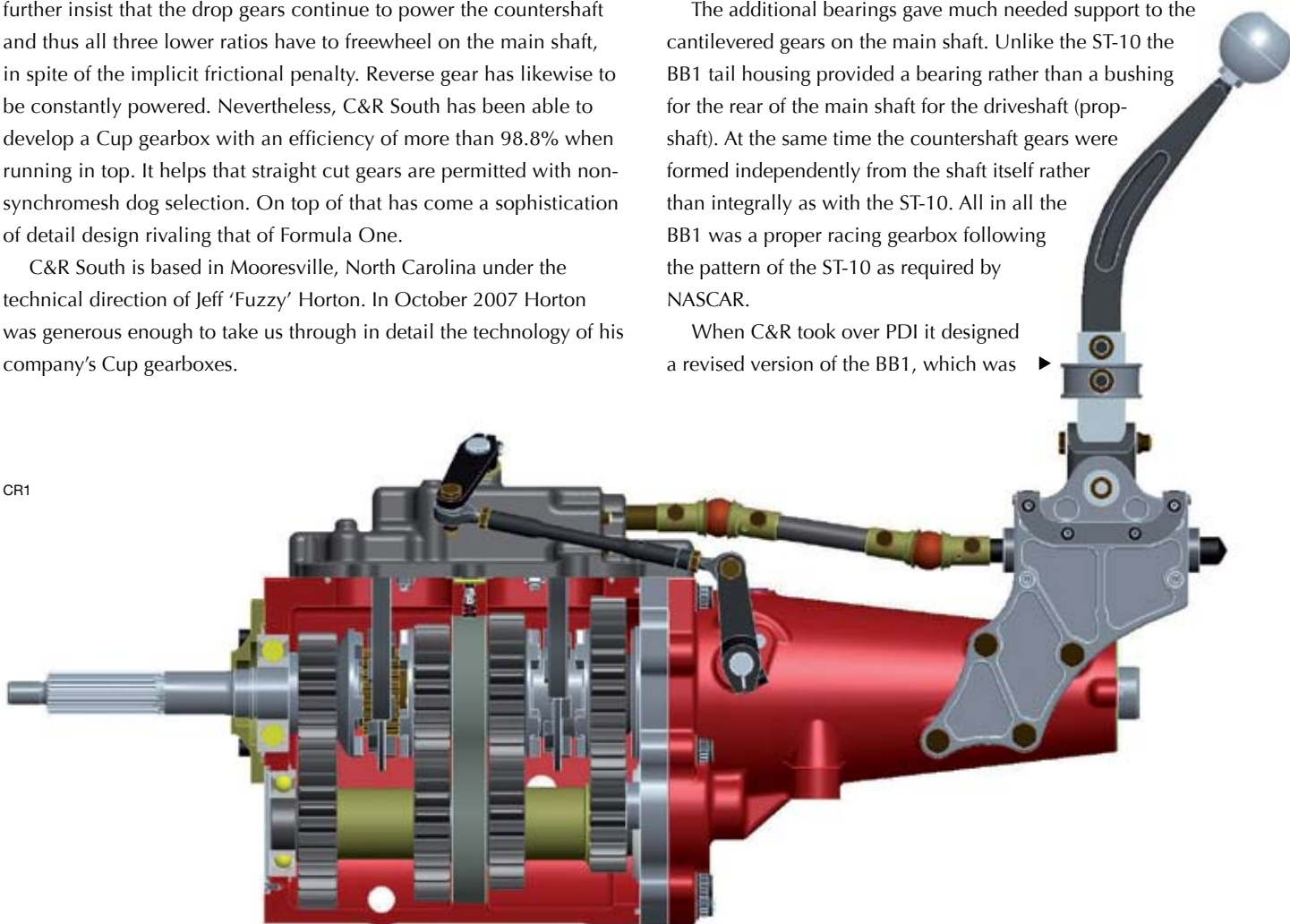
**CR1**

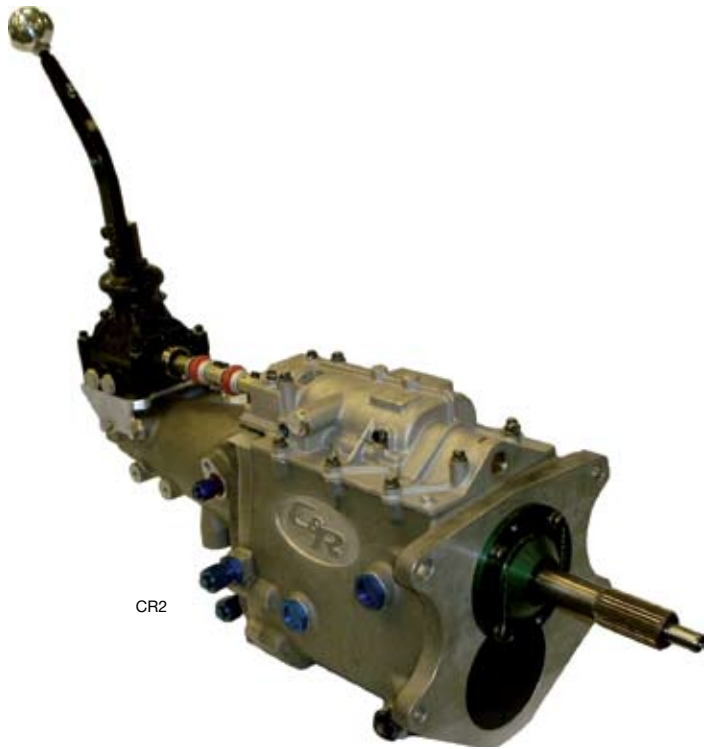
The current C&R South Cup gearboxes are derived from the BB1, which was designed by PDI, the company that Chris Paulson’s C&R concern in Indianapolis bought to create C&R South. The BB1 was a clean sheet of paper design, following the general layout of the ST-10 in accordance with NASCAR practice and taking advantage of straight cut gears with no requirement for synchromesh. It used a top cover rather than the traditional side cover and added a support bearing between second and third gear to both the main shaft and the countershaft. These two bearings ran in a bulkhead cast into the main case, accommodation of which slightly lengthened the case.

The additional bearings gave much needed support to the cantilevered gears on the main shaft. Unlike the ST-10 the BB1 tail housing provided a bearing rather than a bushing for the rear of the main shaft for the driveshaft (prop-shaft). At the same time the countershaft gears were formed independently from the shaft itself rather than integrally as with the ST-10. All in all the BB1 was a proper racing gearbox following the pattern of the ST-10 as required by NASCAR.

When C&R took over PDI it designed a revised version of the BB1, which was

CR1





CR2

called the CR1. The main enhancements were a stiffer top cover and an improved detent mechanism in that cover to assist the shift. At the same time a new three-rail shift mechanism was designed, with a revised layout and detail design enhancements, all of which made for a more precise shift, retaining the mandatory H-pattern.

The CR1 retained the traditional left hand shift location whereas the COT requires an overhead shifter since the driver's seat has to be adjacent to the transmission tunnel. To accommodate this C&R South designed an upgrade kit, which converts the CR1 to CR1-V2 specification. This features a completely revised shift mechanism. It mounts within its top cover a pair of sliding rails that replace the traditional fork-selector cams.

One internal selector rail serves first and second gear while the other serves third and fourth. These two fork rails run parallel and a central overhead finger swings one way or the other to select one or the other of them. Having selected the required rail the finger then slides it fore or aft to attain the required fork position. Thus each gear

“Gear machining and heat treatment were improved and tooth geometry revised, enhancing precision”

## CR2 ANATOMY

Like all currently approved NASCAR gearboxes the CR2 follows the general arrangement of the ST-10. However, it replaces the traditional mid plate by a 'cluster plate', which mounts the rear shaft bearings further forward, benefiting thus from a shorter gear stack and reducing thus the extent to which the ratio gears on the main shaft are cantilevered. The cluster plate is an aluminum casting. This and the case are cast by Olson Aluminum Castings of Rockford, Illinois while the magnesium tail housing is made by Lite Metals of Ravenna, Ohio. Racing transmission specialist Xtrac in England manufactures the gears and the gear shafts.

The CR2 retains the traditional 3.5" gear centre dimension, with narrower gears, which are produced from advanced steel, ground and REM-finished among other processes. Each main shaft ratio gear is attached to a hub that, when it is not selected freewheels on a pair of needle roller bearings.

Each gear dog ring has five dogs, each having a 10-degree back cut and the meshing dog selector ring runs on the main shaft on 10 splines. The 1.75" diameter main shaft is made from Xtrac proprietary steel and is gun drilled. The countershaft is also gun drilled. Its gears run on splines and are positioned by spacers.

The connection to the clutch hub is made by 26 (or alternatively, with larger diameter 29) splines on the front of the input shaft, according to team preference. The input shaft runs on a needle roller bearing in the front plate. The countershaft runs on ball bearings at the front and rear, with a pair at the rear to provide adequate support for the reverse gear. The cluster plate also carries a larger diameter ball bearing for the main shaft. As standard the ball bearings are steel but ceramic is an option.

At the front CR2 mounting is by four steel bolts, which pass through the main case front plate into the bellhousing. The tail housing is attached to the main case, sandwiching the cluster plate, by means of half a dozen dowelled steel studs.

CR2 lubrication is either splash or oil circulation generated by an external but integral pump. A gear at the rear of the countershaft directly drives the adjacent pump. Of the eccentric rotor type, the pump was designed specifically for this application. It collects oil from a scavenge point in the lower cavity of the main case, adjacent to its location. Having pressurized the lubricant to 23 psi (1.5 bar) it feeds it through a dash-8 line, then optionally through an oil cooler to the right hand side of the cluster plate, where there is the entrance to the oil distribution system. This sees lubricant fed through the centre of the main shaft to the bearings and via a rail to the gear faces.

The selector system is housed within the top cover and one single rail operates both forks through its lateral position and rotation. Externally the system looks similar to the CR1-V2 with just a single rail running from shift stick assembly to the top cover but internally it is quite different. A new design of fork enabled the use of a single internal selector rail.

can be selected by the twist and shift of a single finger and in turn that finger, which is also housed within the top cover can be operated by a single external rail running from the shift stick assembly across to the top cover. Thus was the precision of shift enhanced further.

Next came the CR1-V3, which adds enhanced gears to the CR1 package. Gear machining and heat treatment were improved and the tooth geometry revised to further enhance precision and longevity of the gears. In addition the dogs were no longer machined into the gear face. Instead a separate dog plate is used. This is still connected to

## THE ST-10 PATTERN

All contemporary Cup gearboxes follow the pattern of the ST-10. Designed by Borg & Warner as a 1974 upgrade of the 1957 T-10 gearbox, the ST-10 is four speed plus reverse. Its layout sees the input shaft running co-axial with the main shaft. A pair of constantly-engaged drop gears feeds power from the input shaft to a countershaft that runs underneath the main shaft. The countershaft carries the three lower ratios, those gears formed integrally with it. The meshing main shaft ratio gears freewheel until selected. In top gear all three freewheel and the input shaft is coupled directly to the main shaft and consequently the driveshaft will run at the same speed as the engine flywheel.

A front plate, which is bolted directly to the bellhousing supports the input shaft with its drop gear immediately behind it while a 'mid plate' supports the co-axial main shaft with the three ratios ahead of it. Meanwhile the countershaft with its drop gear and three ratio gears is supported at each end by those two bearing plates. A tail housing bolted to the mid plate has at its far end an additional support bushing for the driveshaft.

This arrangement of bearings means that the most forward of the three ratio gears on the main shaft is cantilevered well ahead of the main shaft support bearing. The ratios are arranged third – second – first, front to rear so first has the best support on the main shaft. The ST-10 employs a ball-type bearing for the input and main shafts and uses needle roller bearings for the countershaft. Reverse gear is carried in the front of the tail housing.

The ST-10 is supplied without shift mechanism, which is incorporated into the detachable main case side plate. A fork selects each gear in the normal manner. In turn rotation of a cam moves the respective fork: one cam selects either first or second, another either third or top. There are then normally three rails: one to link the shift lever to each cam and a third to link it to reverse. Pushing a rail forward rotates the cam in one direction to select a gear, pulling it back rotates it the other way to select another. The H-pattern allows one rail to be worked each side of the 'H' together with a system of push down and forward to engage the reverse rail. This 'Three Rail' shift system is also called the 'Long' system after its inventor, Leonard Long.

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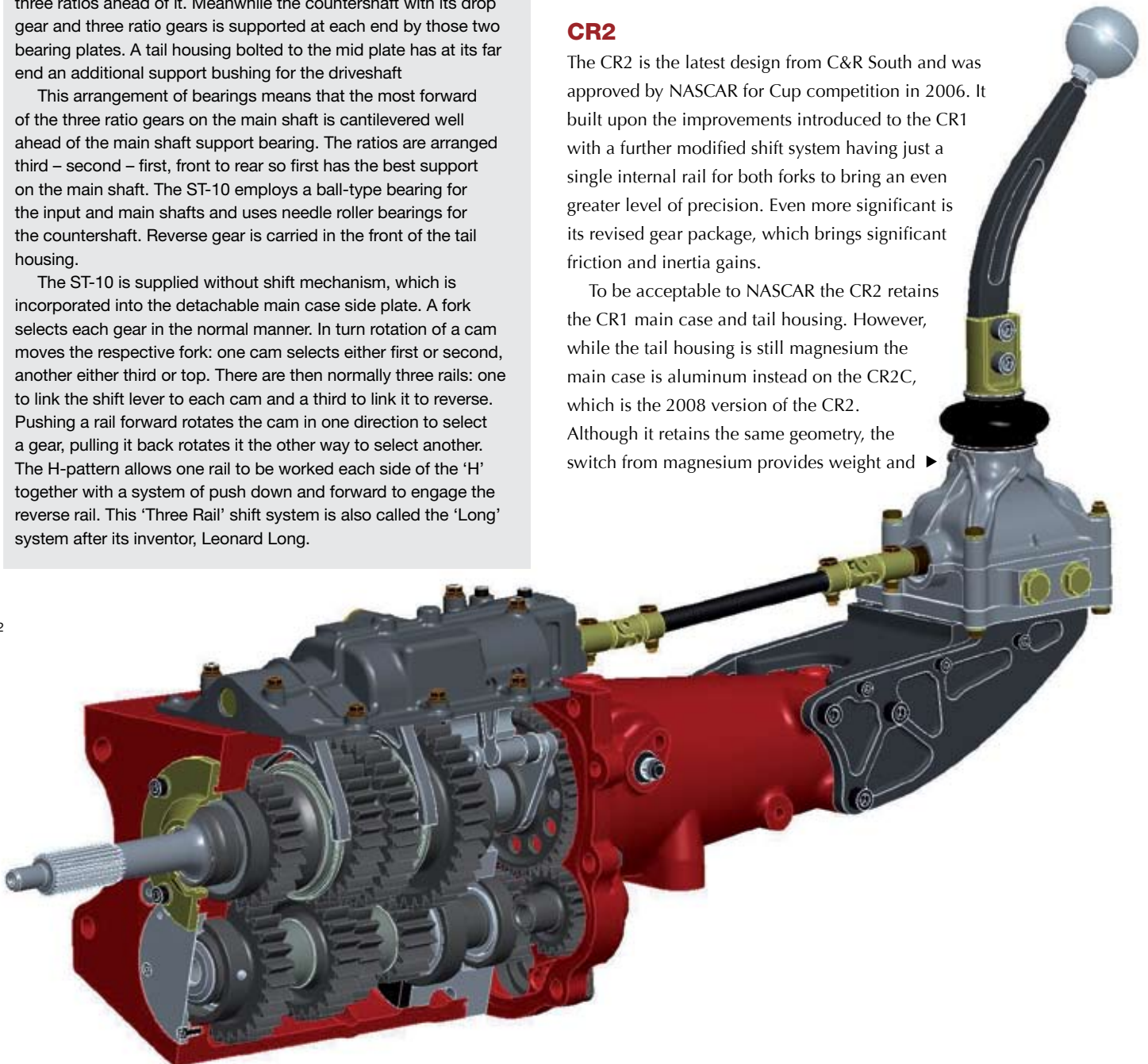
the gear itself by a dog connection but that secondary connection is permanently engaged. The system allows the dog plate to be replaced in the event of dog damage with no need to change the gear itself.

### CR2

The CR2 is the latest design from C&R South and was approved by NASCAR for Cup competition in 2006. It built upon the improvements introduced to the CR1 with a further modified shift system having just a single internal rail for both forks to bring an even greater level of precision. Even more significant is its revised gear package, which brings significant friction and inertia gains.

To be acceptable to NASCAR the CR2 retains the CR1 main case and tail housing. However, while the tail housing is still magnesium the main case is aluminum instead on the CR2C, which is the 2008 version of the CR2. Although it retains the same geometry, the switch from magnesium provides weight and ▶

CR2



In the COT the C&R South CR2 gearbox is normally fitted directly to a 9.25" flywheel, bellhousing/flywheel/clutch assembly, such as that produced by Tilton and described elsewhere on these pages. The main shaft then directly powers the driveshaft through a cross and two yokes-type universal joint supplied by Dynotech to C&R South.

One of the two yokes is a 'slip-yoke' with internal splines to accept the splined end of the main shaft with scope for relative axial movement while the other is a 'weld-yoke', since it is welded to the driveshaft. The splined slip-yoke connection permits fore and aft movement of the driveshaft relative to the gearbox that movement in turn caused by movement of the rear end. Each steel yoke carries a pair of cups that take the respective arm of the steel cross running on needle roller bearings. At the rear of the driveshaft the same basic arrangement is employed with the pinion shaft splined to its yoke and then retained by a nut rather than free to slide.

NASCAR mandates a 4.0" outer diameter steel driveshaft that can have an 0.65" or 0.83" wall thickness. Some teams consider the former too light duty for road courses and short ovals where there is significant acceleration but most are happy to use it everywhere. The driveshaft by regulation has to be painted white for ease of recognition in the event of it parting company with the car. Typically 46.5" long and with 0.65" wall weighing 21 lb complete with yokes it is balanced by Dynotech at 7000-plus rpm. In top gear it runs at crankshaft speed and balancing at a lower speed is not accurate enough and could cause frequency and noise issues at running speed that could lead to failure.

The driveshaft powers a ring and pinion that by regulation follows the pattern of the traditional 9" Ford rear end. Made by Strange, its case is based upon an iron casting that replicates a fifties Ford component and bolts directly to the solid rear end housing, which is a steel fabrication. The pinion shaft runs in a pair of Timken taper roller bearings carried by a bearing retainer bolted to the front of the case

and again a stock Ford design in cast iron.

Each side of the case carries an axle bearing. The case only runs from the front bearing retainer back to the rear axle line and each axle's taper roller bearing is therefore secured behind the axle line by a steel bearing cap, attached to the case by two bolts. C&R is the master distributor for the Ford brand ring and pinion. The ring gear is bolted to the differential (see sidebar: Detroit Locker). Each steel axle has 31 external splines at its inner end whereby it is driven by through the Detroit Locker-type differential. At its outer end the axle has crowned splines, so as to allow for some wheel camber and toe to be imposed by the rear end housing. The axles and the housing supplied by C&R are both made by Speedway Engineering in California. The rear end housing comprises a centre section flanked by axle tubes with a snout on the end of each axle tube, all welded together. The housing carries truck arm mounting pads, brake caliper brackets and the hubs.

Each hub runs on Timken 'Race Pak' ball bearings on the housing's snout. A single nut on the end of the snout retains the hub assembly. The axle projects from its snout whereupon a drive plate picks up its splines. The drive plate is then sandwiched by the hub and the wheel. Five studs project from the hub and pass through the drive plate to the wheel, where the wheel nuts hold the assembly together.

The rear end lubricant is fed through an external radiator. Some teams use an external pump belt driven from the pinion shaft adjacent to the yoke but most run an internal pump, a lighter solution not susceptible to belt damage from debris. The internal pump is fitted to the back of the pinion shaft, which drives it directly (via an 0.3125" hex) and thus it sits within the lubricant. The oil it collects is sent through a hard line out of the housing and thence to a radiator. It is fed back into a port that sprays the cool oil onto the ring gear. C&R supplies a gear-type pump that has Waterman internals inside its own housing.

more significantly stiffness gains.

The CR2C main case deletes the central bulkhead since the intermediate shaft support bearings are removed to reduce friction. On the face of it the removal of those bearings and the use of narrower gears would have permitted the design of a new, shorter case. However, while the CR2, benefiting from lighter rotating internals and lighter case weighs just 63 lb, for 2008 NASCAR has decreed that a COT gearbox must weigh 80 lb minimum.

The deletion of the intermediate shaft support bearings does not

“The reduction of ratio gear cantilever made feasible the deletion of the support bearings”

cause an issue in spite of the cantilevered ratio arrangement since the CR2 benefits from more than a 2.0" reduction in the length of the gear stack, following the introduction of narrower gears. The CR1's countershaft stack of drop gear and three ratios was 9.0" long and in the CR2 it is less than 7.0". Having the same case geometry the CR2 retains the mid plate position of the CR1 but that mid plate is now a 'cluster plate' having integral sleeves that project its main shaft and countershaft bearings forwards, as is permitted by the shorter stack. It is the consequent reduction in the extent to which third and second gears are cantilevered with respect to the main shaft forward support bearing that has made feasible the deletion of the additional support bearings.

The only real drawback is that the more forward position for the rear countershaft bearing calls for an additional rear bearing, to support reverse. Reverse gear is sometimes used by a team to get the car out of the garage, or if the driver overshoots the pit box. Other teams have the mechanics push the car. NASCAR rules require an operable reverse gear and it is common practice to reverse into the pit box during NASCAR's often crowded pit stops.

The narrower forward gears run on the same gear centre distance as the CR1 and ST-10 of 3.5" – it is not an increase of gear diameter (which would in the circumstances be unfeasible) that has permitted the significant reduction of gear width. Rather, it is superior gear design, material specification and manufacturing processes. Where

## “The REM process alters the material and surface characteristics, reducing friction and enhancing strength”

the CR1 internals are made at Industrial Machine and Gear, CR2 production is subcontracted to Xtrac in the UK, which makes many Formula One car gearbox internals. Xtrac uses proprietary steel and grinds rather than hobs the gears. Grinding is more precise than hobbing so the gear doesn't have to be as robust and this and the use of the REM process instead of tumbling and polishing are at the heart of the reduction of gear width.

Xtrac calls the REM Isotropic Super Finishing process, which it exploits in house under license from REM Chemicals Inc, 'Xtrem'. The process alters the material as well as surface characteristics of the component, reducing friction and enhancing strength and in recent years it has been at the heart of a significant reduction in size of Formula One gearbox internals. Applied in conjunction with the right specification steel and manufacturing processes, the upshot is a smaller, lighter gear that can do the same job, with at the same time less friction.

Additionally benefiting from scalloping, the CR2's narrower gears are significantly lighter, reducing inertia. They have only five dogs, compared to eight in the case of the CR1, saving a little more weight; a little less inertia. The same inertia advantage is true of the main shaft, which is gun drilled whereas that of the CR1 is solid. The countershaft, too and in view of this the gears (which run on splines so that they can be manufactured independently of the shaft) are positioned by spacers whereas the CR1 used snap rings. The snap ring groove would have been an issue given the gun drilling of the countershaft.

CR2

### GEARING

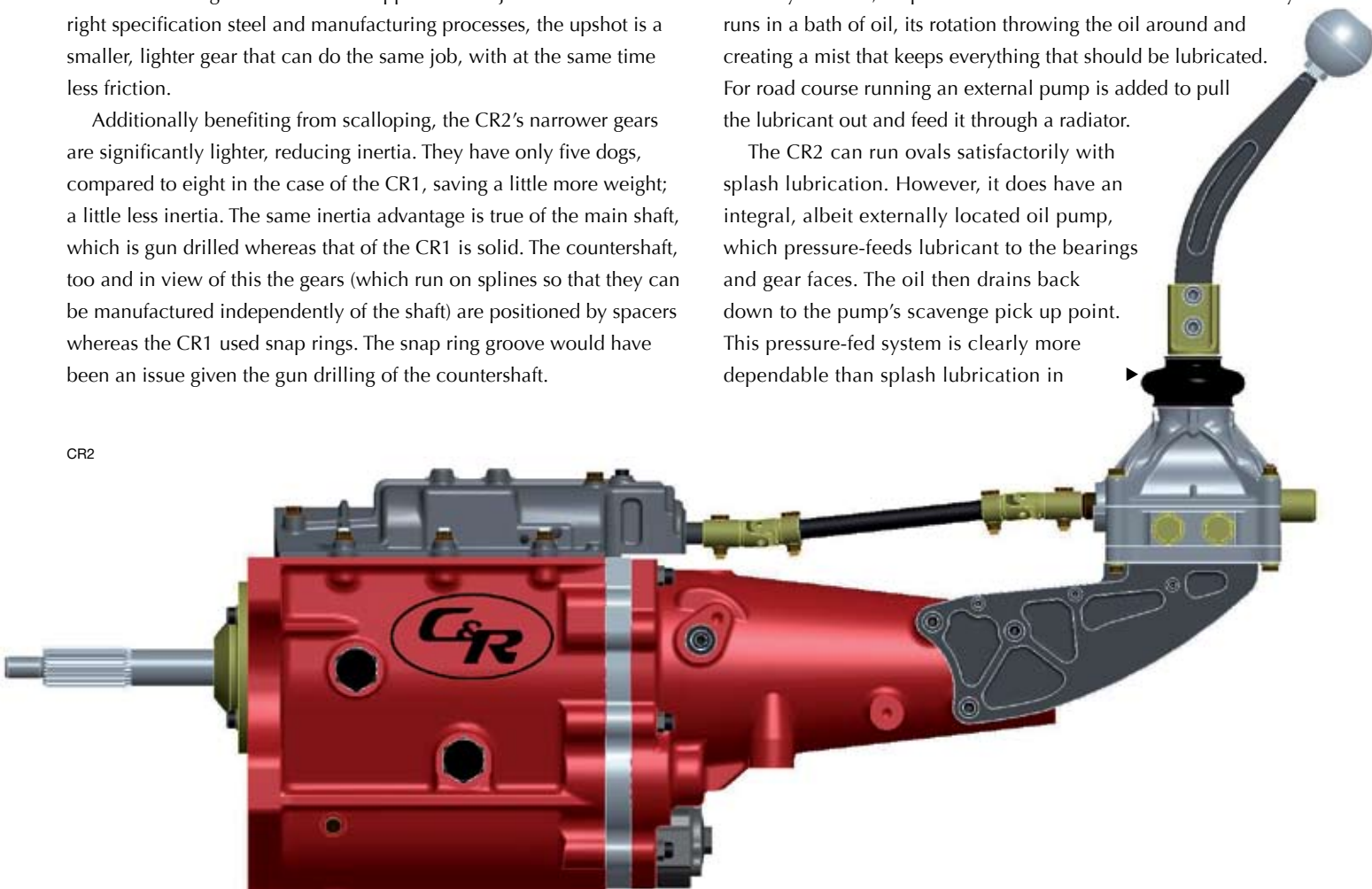
Top gear has to be 1:1 and the overdrive third gears used at some tracks that saw the shift pattern second – fourth – third are no longer permitted. These days third gear has to be no taller than 1.28:1 on an oval, so that ratio is normally used. First gear is then often 2.94:1 and second might be 1.86:1. However, second is used on restarts so some teams will vary it according to the final drive ratio, which has to be one of a choice of two mandated by NASCAR. Final drive ratio can also influence first, which might be varied so that there is not too much of a step to the chosen second when exiting the pits.

However, road courses aside other teams run the same four gear ratios everywhere, regardless of final drive ratio.

The new gears and shafts together with the lack of intermediate support bearings and a re-spec of the retained bearings all add up to a significant reduction of inertia and friction compared to the CR1. The reduction in inertia pays off in terms of acceleration in particular. On ovals the inertia gain is seen at the likes of Martinsville, where there is significant braking and accelerating. The frictional gain is seen everywhere and is most significant at the Plate Superspeedways.

For road racing an external gearbox oil cooler is always used whereas it is not required for oval running due to the lack of shifting. The conventional approach to Cup gearbox lubrication on ovals, as taken by the CR1, is splash lubrication. The countershaft assembly runs in a bath of oil, its rotation throwing the oil around and creating a mist that keeps everything that should be lubricated. For road course running an external pump is added to pull the lubricant out and feed it through a radiator.

The CR2 can run ovals satisfactorily with splash lubrication. However, it does have an integral, albeit externally located oil pump, which pressure-feeds lubricant to the bearings and gear faces. The oil then drains back down to the pump's scavenge pick up point. This pressure-fed system is clearly more dependable than splash lubrication in



## DETROIT LOCKER

C&R South supplies an Eaton-manufactured Detroit Locker-type differential. In essence the Detroit Locker is an on/off device: it is either running as an open differential or else one or both axles are locked to its centerpiece, which in turn is firmly connected to the ring gear.

The ring gear bolts to the Detroit Locker's outer housing and in turn the centerpiece is splined to that housing. Each side an outer-piece is splined to the respective axle. The centerpiece can lock each outer piece through a dog-style drive with spring preload of this ratchet-type mechanism.

There is a choice of Hyperco spring to vary the preload but most teams tend to stay with one for all venues. Likewise most stay with one style of coupling, although the number of dogs can be varied together with their ramp angles. Set up of the Detroit Locker is far from a subtle art since it is violent and often unpredictable in its operation.

Chassis engineering guru, the late Carroll Smith pointed this out. In his excellent book 'Tune to Win' (ISBN 0-85045-808-0) he adds: "Its functioning can be compared to that of the ratchet on a chain fall. As load is transferred it is forever locking and unlocking, causing great lurches and changes from understeer to oversteer. The best thing to do with a Detroit Locker is to remove the center cam and run it locked. End of discussion."

Unfortunately that is not feasible given the Cup rules, which mandate the use of a fully functioning Detroit Locker at all times. Consequently the best that can be hoped for is that the driver uses the throttle in such a way as to avoid bringing its ghoulish nature into play. That is feasible on most oval tracks. The use of a Detroit Locker at Watkins Glen is definitely another story for another time. Halloween?

terms of getting the oil to the right places but there is no history of Cup cars having gearbox lubrication issues on the ovals when the manufacturer's oil levels have been followed. Running with the pump does mean that a smaller volume of lubricant can be employed, reducing windage losses.

At a Plate Superspeedway drivetrain losses come under the microscope, along with engine frictional losses. Teams look at everything in the powertrain, including the likes of rear wheel bearings and transmission oil viscosity. Windage in the gearbox is a significant factor. However, while there is scope to reduce windage loss by the deployment of the CR2's integral pump at the same time driving the pump saps power, so there is a delicate balance of pro and con rather than an automatic gain. Currently C&R South is working with Xtrac to optimize the pump approach, so that it is a clear gain over splash lubrication on the ovals.

The C&R shop is in Mooresville, North Carolina



## BELLHOUSING/CLUTCH: TILTON

Tilton bellhousing/clutch package



## Reduced Ring

### The COT ushers in a smaller bellhousing and flywheel

Tilton announced its 52-Series Driveline Package for the COT at the 2006 PRI Show in Orlando, Florida following its approval by NASCAR for Cup racing from 2007. This package includes bellhousing, flywheel, clutch, clutch release bearing and starter.

As we have seen the COT uses the current Cup engine in a revised chassis, with some revisions to the driveline, most notably a smaller flywheel. The flywheel diameter goes down from 12.835-inch to 9.25-inch, allowing a slimmer bellhousing with more clearance to the track surface. Previously it was not unknown for the bellhousing to wear through from contact with the track surface, sometimes ultimately exposing the flywheel's ring gear.

The new bellhousing is aluminum rather than magnesium by regulation. It is no heavier thanks the reduction in its size permitted by the smaller flywheel. It has a bolt pattern that is now standard for all COT chassis but the engine bolt pattern still varies according to make. The smaller flywheel makes way for a cable drive (as pioneered by Sid Waterman) from camshaft to rear-mounted fuel pump to pass right through the bellhousing.

The smaller flywheel is still steel but its smaller diameter has cut the mass moment of inertia by approximately 60%. The ring gear is built into the Tilton flywheel and is operated via a twin shaft gear arrangement. This provides more gearing reduction between starter and ring gear than was the case when using the larger flywheel. The same starter motor is retained with the new drive system.

As before the cars use a 7.25-inch three plate metallic clutch. Tilton's Cup clutch and its hydraulic release bearing were introduced three years ago, so are proven items. The latest iteration of Tilton's Cup clutch has some refinements to improve heat management. "With Cup cars torque is not a problem, the challenge is the heat and abuse that the clutch faces," remarks Tilton Managing Engineer Mike O'Neil.