WA Technology

eLSD (Electronic Limited Slip Differential) Vs Positraction

The C8 and C7 Use A New Way To Manage The Differential

GM's eLSD was NOT developed for the high-performance Corvette. A 2007 SAE technical paper stated it was first used in a few GM FWD cars! Quoting from the introduction of the paper:

"Limited-slip differentials improve traction and handling when compared to open differentials but offer no active modulation and can compromise typical driving. Electronically controlled limited-slip differentials (eLSD) are being introduced that allow active control of the differential in all driving situations and can be operated as an open differential, a fully locked differential, or at any point between these extremes.

Such an eLSD system was implemented in two General Motors front wheel drive cars-one on an automatic transmission and applied by the transmission pump, the other on a manual transmission and applied by an external pump. This eLSD system contains a multi-plate wet clutch connected to the differential carrier and right-side half-shaft of an all-wheel drive capable transmission."

My Experience with FWD: When I could only get gas every other day based on the last digit of my License Plate number (odd or even) I could not make it from CT (*where I worked and lived*) to LaGuardia Airport on one tankful of gas in my CJ5 V8 Jeep, headers big off-road tires with 12-gallon tank! I traveled a lot and stayed an extra day out-of-town a few times because I could not buy gas to drive home! High fines for the gas station if they sold gas to a car on a date that was "illegal!"

Bought what was called a "Pocket Rocket." A turbocharged sub compact. That 1900 lb Colt could get 35+ mpg with its 8 speed (*twin stick 4 speed with 2 speed O D in any gear)* manual and just over 100 hp. They used two drive shaft lengths in attempt to control torque steer. But when I put on the Plus 1 wider Pirelli P7s had to be ready to steer quickly or change lanes when taking off fast from a light or go off the road when accelerating after an apex. In fact, learned to use the emergency brake lever (*with the lock button pushed in*) to make turns and counter the tremendous understeer. Pulled the brake in the turn, which caused extra load on the rear tires, and it slide out like my modified Corvair! When it was pointed where you wanted, pressed the accelerator! Can see where eLSD would be a great help!

BENIFT OF eSLD in C8 and C7 Stingray: **The Vette eLSD takes inputs from many sensors that feed info to a computer defining which clutch pack gets how much coupling. Won't get ahead of an explanation but suffice to say it MAY BE more important to the average C8 owner that a Tracker or Racer!**

For example, an Appendix is provided with lots of detailed info about the eLSD. One short, just over a minute, video is a presentation by Jason Kolk a Chevy Performance Engineer in eLSD Integration. Of the many inputs that are optimized for the ME C8 Corvette includes integrating tire temperature (*based on tire pressure changes)* so that stability is based on tire traction when cold and hot! He indicates they have a lot of band width they can control.

Links to his video and one from Professor John Kelly that covers 11 types of traction control differentials is also provided. He has the actual products and notes most use a principle developed by Dana Corporation in the 1950s of clutch packs on either side of the differential. That is what Chevy called *"Positraction"* and others used the same type but called it different names. Oldsmobile called in *"Anti-Slip,"* Pontiac *"Safe Track,"* Chrysler *"Sure Grip."* He shows they are activated but what I jokingly refer to as "Sloppy Mounted Spider Gears." In fact, most rely on the spider gears not only having tortional loads when the wheels are going at different speeds but also lateral forces that push the spider gears into the side gears. That compresses the clutch packs causing the wheels to operate more or less together. Actually, they don't every reach that condition or gear side pressure would reduce without coupling. One downside of what GM calls Positraction and has since 1960s. Positraction is what you get in the Base C8!

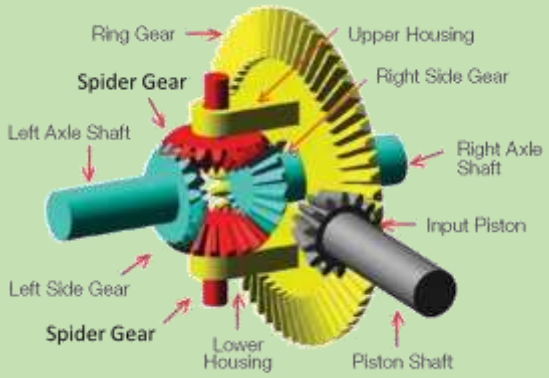
Professor Kelly also discusses how the Torsen gear differential works. Have seen attempts to show how it works that were confusing. It's simple, it relies on 4 very long gears and 4 somewhat shorter gears BUT they, similar to spider gears, move slighlty in their passages and provide a locking mechanism! He also shows an interesting Toyota differential that works with two clutch packs like Positration BUT they are operated with clutch folks much like the clutch in a manual transmission.

THE APPENDIX also has a several pages from a Forum Post by Tadge re eLSD. It's actually about the eLSD dash display and written by Jason Kolk (mentioned above.)

A knowledgeable engineer BUT it will take several readings and making notes to follow just what he is saying! He provides much more than the subject of the eLSD Display.

Photo Sequence Starting From The Beginning

Before we tackle even the simple Positraction "Limited Slip" differential, it's good to start with what is called and open differential. That is what is used to transmit torque when both wheels are on the same good traction surface. It uses what are called Spider Gears (Red) that when even torque can be applied to the Side Gears (where the axles are attached) just rotate with the large ring gear (Yellow.)



Note the spider and side gears are actually located in what is called a carrier (shown pic upper right.)

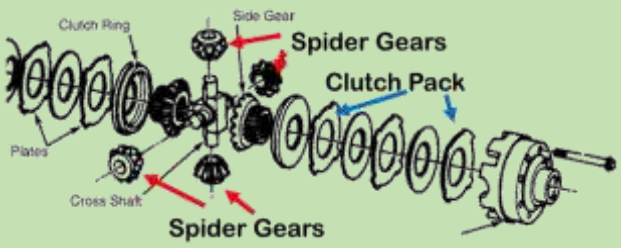
However, when going around a corner, where the outer wheel must go faster than the inner wheel, the spider gears just rotate on the side gears and allow that to occur. That's good. BUT not good if one tire is in mud as that tire will slip and spin and the other will do nothing! Hence you go nowhere!

Recall in "My Cousin Vinny," one wheel spun in Mud and the other did not turn! His Caddy had an "Open Differential."

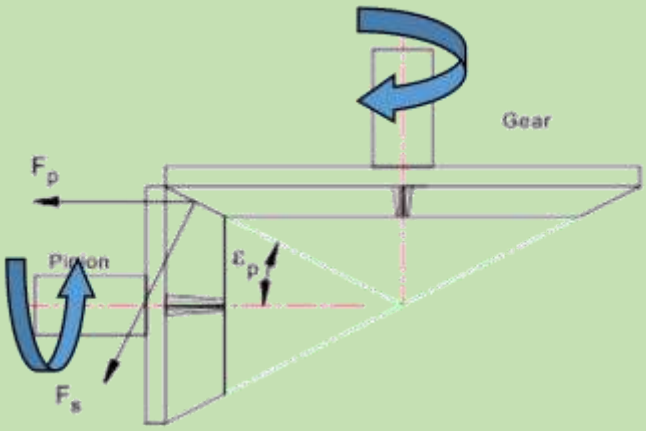
Positraction or "Posi" for Short

GM and the other car companies solved the problem (well mostly) with a device that Leandro DaVinci would have been proud of! Zero electronics, all mechanical! When transmitting tortional load and one wheel is going at a different speed the spider gears also have an axial load and the press on the side gears. In pic right there are 4 spider gears that will press on the side gears splined to the two axles. (Pic below frame may help that understanding.)

In this case the side gears press on a pack of clutches and fixed plates, like those in a "Slushbox" Automatic Trans. They can partially lock both axles together hence achieve "Limited Slip." No feedback, the slipping wheel generates the forces!



1960s = C8 Positraction



Although the intent of two right angle bevel gears (*like the spider and side axle gears*) is to generate tortional load from one gear to the next there is also an axial force trying to push the gears apart (F_p.)

In the case of the differential side gears, in a Posi they are splined to the axle and can slide on their pinion shaft. In a Posi the side gears move and load a clutch pack that causes the carrier to partially lock both sides together.

eLSD

The eLSD is totally different that Positraction. It still has two clutch packs, on each side of the combo Dif Trans DCT. BUT the clutches are operated like everything else in the car by a computer! They operate by activating up to 3000 psi (*that is what it was in the C7 and probably similar in the C8.)* It can lock one side or both and unlike Posi create a 100% lock. However, its benefit comes from operating each only the amount needed!


Right eLSD Clutch Pack. Activated with ~3000 psi Using Many Sensors in 0.1 Sec. Locking Both if Commanded.

Quoting a few points from the three pages from Jason Kolk in the Appendix: "*There is a lot going on behind the scenes in the software to come up with the eLSD coupling that you're seeing Pic left from the C8 display. A number of algorithms that are running at the same time to collectively decide how much coupling is needed for the different vehicle dynamics situations that they each monitor and control. Logic is used to decide which one of them wins out or which ones add together to deliver the final command that you see on the display and feel in the car."*

"The eLSD can have subtle but profound effect on handling of the c8. It's considered a 'basic chassis' component. It something that plays a big part in setting up the character of the car. Off-throttle, more eLSD coupling adds stability, but too much can be a bad thing. The eLSD is connecting the two wheels so in a turn it's trying to slow down the outside wheel and speed up the inside wheel. In other words, the eLSD clutch coupling is trying to oppose the direction that the car is turning, so setting this off-throttle level is pretty important to keeping the car feeling agile. In a steady turn this can help tune the amount of understeer the car has. In highly dynamic maneuvers, this results in something that we call yaw damping where it will reduce the rotation rate of the car."

"*When the driver is on-throttle, the eLSD clutch can shift torque from the inside wheel to the outside wheel. This has the combined effect of minimizing or eliminating inside wheel spin, but it also controls how much it feels like the car turns with the throttle. More torque on the outside and less on the inside will help the car turn - to a point, but that's the balance we're constantly searching for while we tune the software.* **Enough from Jason Kolk, you can read his whole Forum Post in the Appendix.**

These are additional comments from knowledgeable folks reviewing the eLSD system:

"A smart electronic limited-slip differential (eLSD) is included in the Z51 Performance Package and continuously optimizes the torque split between the rear wheels. The system features a hydraulically actuated clutch that can infinitely vary clutch engagement and can respond from open to full engagement in tenths of a second. It shifts torque based on a unique algorithm which factors in vehicle speed, steering input and throttle position to improve steering feel, handling balance and traction. The eLSD is fully integrated with StabiliTrak and Performance Traction Management systems. Its calibrations vary among three modes, based on the Drive Mode Selector setting:

- *Mode 1 is the default setting for normal driving and emphasizes vehicle stability*
- *Mode 2 is engaged when electronic stability control is turned off in the Sport or Track Driver Modes. This calibration enables more nimble turn-in and traction while accelerating out of a corner*
- *Mode 3 is automatically selected when Performance Traction Management is engaged. This calibration has the same function as Mode 2 but is fine-tuned to work with Performance Traction Management."*

Appendix

There are some excellent video's than can bring you up from no understanding of a differential to more than you may want to know:

Very simplistic Video defines why a differential is needed and how it's constructed:

https://www.youtube.com/watch?v=LpX9dBglvVw

How Positraction Works:

https://www.youtube.com/watch?v=LpX9dBglvVw

Professor Kelly Reviews 11 differentials and how they work (1 hour.)

https://www.youtube.com/watch?v=1a9JQC6fgXw

Jason Kolk; Chevy Performance Engineer eLSD Integration (short 1 minute.)

https://www.youtube.com/watch?v=kEYsdmCE3N4

Tadge Answers With A Forum Post A Question About eLSD Display

Many people have asked about that eLSD display. Electronic limited slip differentials (eLSD) have only been introduced relatively recently, so many are unfamiliar with the details of their operation. The Corvette is a very sophisticated machine, and we try to provide instrumentation that is accurate, readable and informative about the hardware. When we first decided to add eLSD to the 7th generation Corvette, we started thinking about how we would inform drivers about its operation and decided an added display might be interesting to some customers. Generally speaking, we try to calibrate our chassis controls so that they are virtually invisible to the driver. The idea is to integrate our electronic and mechanical systems to the point where the Corvette just feels like a naturally great handling car - intuitive and benign without unwanted interventions that take the fun out of driving.

Normally I write answers on the forum myself and check in with appropriate experts for additions or suggestions. I can't take any credit this time. Our eLSD integration engineer, Jason Kolk, provided a detailed answer below. He is one of several chassis controls engineers who calibrate the chassis controls to great effect on the Corvette.

Also, I would be remiss if I didn't remind everyone that the eLSD does some of its most important work in some pretty aggressive maneuvers. That is not the time to be looking at the display.... First priority is to keep eyes on the road!

Jason Kolk Performance Engineer eLSD Integration Answered (*also added operation info*)

The eLSD dash display (left) provides two pieces of information on the display, eLSD clutch coupling percentage value on top in yellow, and the slip percentage of the rear wheels on the bottom in white shown in the bar graph.

<u>eLSD Percentage in the top/middle:</u>
In the center there is an image of the car, two wheels and the differential. The differential lights up as the eLSD coupling increases. The value shown is a percentage of the full locking coupling capability, and it is the actual value reported by the actuator. When we calibrate eLSD, we work in units of torque. 100% corresponds to 2000 Newton-meters (1475 ft-lbs) of break-away torque (every 1% is 20 Nm (14.75 ft-lbs)). Said another way, while holding one wheel stationary it would take 2000 Nm of torque on the other wheel to make the clutch between the two wheels slip if the display read 100%. For reference a C6 mechanical differential clutch pack was roughly 120 Nm (88 ft-lbs). The actuator is very quick to respond and is able to change from open to locked (0 to 100%) 150 ms (.15 sec) in order to respond to any dynamic situation.
There is a lot going on behind the scenes in the software to come up with the eLSD coupling that you're seeing here. There are a number of algorithms that are running at the same time to collectively decide how much coupling is needed for the different vehicle dynamics situations that they each monitor and control. We have some logic to decide which one of them wins out or which ones add together to deliver the final command that you see on the display and feel in the car.

At the most basic level, the eLSD can have a subtle but profound effect on the handling of the car. We really consider it to be a 'base chassis' component. It's something that plays a big part in setting up the character of the car.

- Off-throttle, more eLSD coupling adds stability, but too much can be a bad thing. The eLSD is connecting the two wheels so in a turn it's trying to slow down the outside wheel and speed up the inside wheel. In other words, the eLSD clutch coupling is trying to oppose the direction that the car is turning, so setting this off-throttle level is pretty important to keeping the car feeling agile. In a steady turn this can help tune the amount of understeer the car has. In highly dynamic maneuvers, this results in something that we call yaw damping where it will reduce the rotation rate of the car.

When the driver is on-throttle, the eLSD clutch can shift torque from the inside wheel to the outside wheel. This has the combined effect of minimizing or eliminating inside wheel spin, but it also controls how much it feels like the car turns with the throttle. More torque on the outside and less on the inside will help the car turn - to a point, but that's the balance we're constantly searching for while we tune the software.
Each package is tuned individually so a Z06 won't have the same values as a Stingray Z51, for example. Automatic and Manual transmissions have different calibrations, and even suspension and tire packages like FE3 and FE4, FE6 and FE7 do differ from each other.

eLSD is fully integrated with the stability control and Performance Traction Management (PTM) systems.

Note that changing from Tour to Sport to Track has no effect on eLSD mode. eLSD mode does change automatically when the Traction Control button is pressed. No unique input from the driver is required.

- eLSD Mode 1 is the standard mode when the vehicle is started. It is optimized for how torque is delivered with Traction Control active and off-power there is an emphasis on vehicle stability. Mode 1 is also used in Performance Traction Management Wet mode.

- eLSD Mode 2 is engaged when both Traction Control and Electronic Stability Control are turned off. This calibration provides nimbler corner turn-in and is optimized for traction out of corners.

- eLSD Mode 3 is engaged when Performance Traction Management is in Dry, Sport 1 & 2, and Race modes. Off power this is a nimble calibration with similar functionality as eLSD Mode 2, however, it is integrated to work with Performance Traction Management when the driver is on power.

eLSD Mode 4 is engaged when Traction Control is selected off, but stability control remains on. Vehicle stability is still the priority, while allowing for optimized traction out of corners.

Here are some examples of what you may see if you watch this screen. I'll talk generally, so the numbers may not match exactly what you see, but the trends should be there:

• Bleed events. The actuator needs to bleed small amounts air out of the hydraulics every few keys cycles to keep things operating consistently. As a driver you may see a couple of spikes to 100% at very low speeds while going straight. This is totally normal and can only happen in a relatively small range of steering on-center, so you won't feel it in tight parking lot maneuvers.

• Driving straight down the road, we have some speed-based preload to add stability and on-center feel. This is going to be relatively small, and you will only see a small amount around 10-15% at highway speeds. You'll notice that when you do steering inputs and simple lane changes that it drops down slightly and then pops back up when you are going straight again. This strategy is to improve steering feel and agility. We can be more open at low speeds than previous fixed clutch packs (C6 was fixed at 120 Nm (88 ft-lbs)), and then add more at very high speeds to add stability.

• On larger throttle applies you will see eLSD clutch torque grow, and these could be the largest amounts of eLSD coupling that you'll see under normal circumstances. On track this could go as high as 40-50%. The goal of this algorithm is to maximize rear traction while cornering and tune the feel of how much the car is turning while you're on power.

• The largest eLSD coupling will happen under very extreme lane changes and slaloms where we can nearly lock the eLSD clutch to add stability at just the right moments, but open back up to allow the car to steer through double lane changes at just the right times.

If you were to drive your car in the winter and start with one wheel on ice and the other on bare pavement, you may see clutch torque build in response the wheel on ice slipping to keep it under control and to maintain smooth

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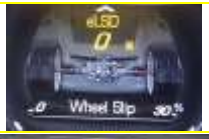
"56" C8, 2017 Grand Sport & 2014 Z51 Stingray Mods, Info Available As PDFs:

56 PDFs discuss improvements or info about a C8, 2017 Grand Sport, 2014 Z51 Stingray function and/or esthetics. Some are minor and others, like the installing "Low Dust Brake Pads" on C8 & C7s, have detailed information.

Below are the PDF's available. Click on picture or Blue PDF link or copy and paste the PDF link (Blue type) into your browser. Or email me at GUttrachi@aol.com **and state the title desired, shown in Yellow:**

C8 Install High Wing ***How To Remove Rear Bumper- Install Wing*** **http://netwelding.com/C8_High_Wing.pdf**	
C8, C7 eLSD vs Positraction ***eLSD is a Modern Dif; Positraction is from 1960s*** **http://netwelding.com/eLSD _VS_Posi.pdf**	
C8 FWD Hybrid ***WFWD Hybrid Provides More Power & MPG*** **http://netwelding.com/C8_FWD_Hybrid.pdf**	
C8 Edge Red Engine Cover ***Engine Cover Matches Valve Covers*** **http://netwelding.com/Engine_Cover.pdf**	
C8 Engine Compartment Lights ***Multicolor Lights Remote operated*** **http://netwelding.com/Engine_Lights.pdf**	
C8 Side Skirts & Splitter ***Install C7 Carbon side skirts & splitter on C8*** **http://netwelding.com/Side_Skirts.pdf**	
C8 Z51, GS/C7 Z51Ceramic Brake Pads ***Performance Vettes have dusty brakes. These help!*** **http://netwelding.com/Ceramic_Pads.pdf**	

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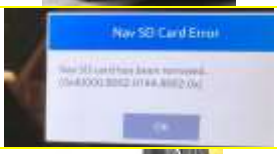
C8 Low Restriction Air Intake ***Low Restriction Air Filter Why & How To*** **http://netwelding.com/C8_Air_Intake.pdf**	
C8 & C7 Splitter & C8 Condenser Mesh ***Mesh Protects AC Condenser & Splitter Install*** **http://netwelding.com/CF_Splitter.pdf**	
C8 NAV SD Card Removed Error ***Error When SD Card and Reader Are Fine*** **http://netwelding.com/NAV_SD_Card.pdf**	
C8/GS/C7 Splash Guards ***GM splash guards. ACS Best Front Guards for GS.*** ***http://netwelding.com/Splash_Guard.pdf***	
Jacking a C8/GS/C7 Vette ***Safely jacking either front only or back & front*** ***http://netwelding.com/Jacking_A_C7.pdf***	
C8 & C7 Plates & Frame; **Must Meet South Carolina Law** **http://netwelding.com/License_Plate_Frame.pdf**	
Change GS/C7 Oil ***WHY change your own oil and C7 Lifting Methods*** **http://netwelding.com/Changing_Oil.pdf**	
C8/GS/C7 Mirror Proximity Alarm ***Limit switch alarm warns when close to door frame*** **http://netwelding.com/Mirror_Proximity_Alarm.pdf**	
Jacking Pads for C8/GS/C7 ***Manual says Jacking Pads 2 1/2-inch max OD..*** **http://netwelding.com/Jacking_pads.pdf**	
C8/GS/C7 Radar Power ***For C7 tapped rear fuse panel. For GS tapped mirror*** **http://netwelding.com/Radar_Detector_Power.pdf**	
C8 & C7 Wheel Chatter/Hop ***Why sharp, low speed turns with cold tires causes the front tires to chatter/hop.*** ***http://netwelding.com/Wheel_Chatter.pdf***	
C8/GS/C7 Wheel Locks ***Wheel locks, help protect your expensive wheels.*** **http://netwelding.com/Wheel_Locks.pdf**	
Deer Whistle Installed on C8/GS/C7 ***Do they work? Plus Install Info*** ***http://netwelding.com/Deer_Whistle.pdf***	
C8 & C7 Splitter Protector ***Scrape Armor Protection for Splitter*** **http://netwelding.com/Splitter_Protectors.pdf**	

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C8 & C7 Cargo Area *Rear cargo area storage device and rear protector* http://netwelding.com/Rear_Cargo_Area.pdf	
C8 Coilover Tower Covers *Prevent water from filling Cast aluminum cavities* http://netwelding.com/Tower_Covers.pdf	
C8.R Info & GS Rear Diffuser (Fits Any C7) *Rear Carbon Flash Composite Diffuser* http://netwelding.com/Rear_Diffuser.pdf	
GS/C7 Belt Rattle *Passenger seat belt rattles against the seat back.* http://netwelding.com/Eliminate_Rattle.pdf	
Aluminum C7 Chassis and Weld Repair *The C7 aluminum chassis. Includes weld repair info.* http://netwelding.com/Aluminum_Chassis.pdf	
Manage GS/C7 Spilled Gas & Door Lock *Protect when filling gas. Preventing door lock failure.* http://netwelding.com/Manage_Spilled_Gas.pdf	
GS/C7 License Plate & Cargo Lights *LED license plate light & cargo area bulbs* http://netwelding.com/License_Plate_Light.pdf	
GS/C7 Door Panel Protector *Black plastic protector prevents scuffing of door* http://netwelding.com/Door_Panel_Protector.pdf	
GS/C7 Improved Cup Holder *A solution to the cup holder spilling* http://netwelding.com/Improved_cup_Holder.pdf	
C7 Carbon Fiber Grille Bar *Install genuine carbon fiber grille bar overlay* *http://netwelding.com/CF_Grille_Bar.pdf*	
Replacing C7 Battery *Tricks for installing battery!* http://netwelding.com/Battery_Issues.pdf	
GS/C7 Window Valet *Lower Windows With FOB Helps Latch Hatch* http://netwelding.com/Hatch_Latch.pdf	
GS/C7 Blind Spot Mirror *Smaller rear and side windows cause C7 blind spots. Small "blind spot mirrors" help* http://netwelding.com/Blind_Spot.pdf	

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GS/C7 Skid Pad Protector ***After the air dam, the aluminum "skid pad" hits*** **http://netwelding.com/Skid_Pad_Protector.pdf**	
GS/C7 OnStar Lights ***Rear view mirror OnStar LED's, at a quick glance, look like a police car flashing light! This is a fix.*** **http://netwelding.com/OnStar_Lights.pdf**	
GS/C7 Skip Shift Eliminator ***Skip Shift Eliminator install with suggestions on jacking a C7.*** **http://netwelding.com/Skip_shift_Eliminator.pdf**	
GS/C7 Catch Can & Clean Oil Separator ***What is Coking and how to reduce the potential*** **http://netwelding.com/Catch_Can.pdf**	
GS MGW Flat Stick Shifter ***The MGW shifter shortens throw and is more precise*** **http://netwelding.com/MGW_Shifter.pdf**	
GS/C7 Round Shift Knob ***A round shift knob shortens throw on OEM shifter*** **http://netwelding.com/Shift_Knob.pdf**	
GS/C7 Stingray Sill Plate ***Stingray sill plate replaces original.*** **http://netwelding.com/Sill_Plate.pdf**	
GS/C7 Nylon Bra ***Nylon Bra Stops Bugs. Fits with Stage 3 Winglets*** **http://netwelding.com/Nylon_Bra.pdf**	
GS/C7 Clutch Fluid Change ***Clutch fluid after 3000 miles gets dirty*** **http://netwelding.com/Clutch_Fluid.pdf**	
C7 Carbon Fiber Hood Vent ***Replaces Plastic Hood Vent*** **http://netwelding.com/Hood_Vent.pdf**	
GS/C7 Cold Air Intake ***Low Restriction Air Filter & Duct*** **http://netwelding.com/Cold_Air_Intake.pdf**	
GS/C7 Soler Modified Throttle Body ***For Improved Throttle Response*** **http://netwelding.com/Soler_Mod_TB.pdf**	
Garmin GPS for GS Cubby ***Garmin Mounts in GS Cubby & Apple CARPLAY*** **http://netwelding.com/GPS_In_Cubby.pdf**	
GS Splitter Stage 3 Winglet ***Stage 3 Winglets Integrate with Spats*** **http://netwelding.com/Stage_3_Winglets.pdf**	

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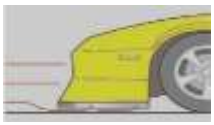
C7 Removing GM Plastic Film ***How To Remove The Rocker Panel Film*** **http://netwelding.com/Rocker_Panel_Film.pdf**	
GS 2LT to 2.5 LT ***Red Upper Dash Pad Like 3LT*** **http://netwelding.com/Red_Dash_Pad.pdf**	
Jake Emblem/Decals for GS ***Jake Symbols Support GS Racing Image*** **http://netwelding.com/Jake_Emblems.pdf**	
Rusty GS/C7 Muffler ***Why the C7 muffler rusts way to turn matte black.*** **http://netwelding.com/Muffler_Rust.pdf**	
GS Engine Compartment Mods ***Cosmetic Additions in Engine Compartment*** **http://netwelding.com/Engine_Compartment.pdf**	
GS Vitesse Throttle Controller: Fits All C7s ***Adjustable Throttle-by-Wire Control*** **http://netwelding.com/Throttle_Control.pdf**	
Boomy Bass Solution ***Use Presets to Adjust Bass etc. Tone/Balance*** **http://netwelding.com/Boomy_Bass**	
GS/C7 Air Dam, Functions ***Why Missing from Z51, Some GS & Z06*** **http://netwelding.com/Air_Dam.pdf**	
Rusty GS/C7 Muffler ***Why the C7 muffler rusts way to turn matte black.*** **http://netwelding.com/Muffler_Rust.pdf**	
Engineering a ProStreet Rod ***How Our '34 ProStreet Rod Was Designed and Built*** **http://netwelding.com/Engineering%20Street%20Rod%203-08.pdf**	
Motorsports Welding Article ***Wrote a 5 Page Article for AWS March 2018 Journal*** ***Covers NHRA and NASCAR Chassis Design*** **http://netwelding.com/Motorsports_Welding_2018.pdf**	

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