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Suspension Geometry & Vehicle Dynamics Report

Vehicle Make & Model: **Ferrari 225S 1952**

Client: **Thomas Schnitzler / Edy Wyss Eng.**
Preparation: **Thomas Schnitzler / Edy Wyss Eng.**

Date of Visit / Measurement: **20/09/2018**
Date of Report: **24/09/2018**

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1.0 Summary & Recommendations

1.1 Summary

This is a rare and beautiful car. The current set up is generally good, but significant improvement is possible.

The car will be used for racing and events as the Tour Auto. See Section 9.0 for the tarmac rally set up.

The chassis is an unusual structure, more complex than the usual Ferrari oval tube ladder frame. The large diameter tubes are widely spaced and are not longitudinally continuous. There is some triangulation - and elements of stressed skin structure in places. The chassis is robust – and though we have not measured it, we think that it is stiffer than other Ferrari chassis of the period. The chassis is known as the 'Tuboscocca' chassis.

Front suspension is by dual unequal length wishbones, a transverse leaf spring operated by the lower wishbones and Houdaille rotary / lever arm dampers operated by drop arms from the lower wish bones. A front anti-roll bar is fitted. Rear suspension is by live axle and half-elliptical leaf springs on swinging hangers, again with Houdaille rotary / lever arm dampers. Longitudinal location is provided by twin radius rods per side, while lateral location is provided by the leaf springs exclusively.

Tyre contact patch load per unit area is very well matched to weight distribution.

Key issues adversely affecting performance:

1) The car is fitted with a Cam and Pawl LSD. These are rarely used today for good reason. See Section 10.0 for an explanation.
2) Front ARB too soft.
3) The combination of front spring and bump rubbers is stiffer than ideal, but only because the bump rubbers are compressed too far at static ride height.
4) High rear roll centre.
5) Poor front roll camber correction.
6) Front suspension pitch geometry gives pro-dive.
7) Steering geometry gives toe-out in bump (roll understeer).
8) The rear springs are too soft.
9) The team has fitted excellent rear bump rubber cradles, but the bump rubbers are too stiff and clearance too large at SRH.
10) We tested damper force / velocity using a simple drop test. The front dampers are much too stiff and very different side to side. The rear dampers are close to the required stiffness, but again very different side to side.

The car turns in well with good initial transient response and is quite well balanced at the apex. The Cam and Pawl LSD causes initial understeer under power in the corner exit phase – over application of power can then cause a rapid transition to oversteer.

While the car is reasonably well balanced, it rolls to 2.4 degrees and tyre efficiency is impaired by poor roll camber correction and excessive contact patch load variation caused by the over compressed front bump rubbers and stiff dampers.

Our recommendations (see 1.2 below) – should result in improved tyre efficiency, grip, balance and driveability. Roll will be reduced from 2.4 degrees to 1.7 degrees.

The car has excellent potential. **Please see section 9.0 for tarmac rally setup recommendations.**

Recommendations include lower front ride height and a much stiffer front anti-roll bar. We recommend retaining the existing springs, but fitting carefully selected bump rubbers and two additional leaves to each rear

spring. It will be necessary to reset / revalve the dampers on a dynamometer. We also recommend fitting a ramp and plate LSD.

Our simulations indicate that, with (race setup) recommendations implemented, on new tyres, a 'perfect' lap at Goodwood would be 1 min 34.69 secs.

1.2 Key Recommendations (Race Setup, Dunlop Tyres)

a) Set front static ride height to 178 mm under the chassis cross member 850mm behind front axle centre line. This should be achieved by removing the 12 mm aluminium plate above the leaf spring centre clamp.
b) Retain existing front leaf spring.
c) Retain existing front bump rubbers, but modify reaction plates on lower wishbones to give 6 mm bump rubber compression at static ride height.
d) **Fit new 24 mm OD solid front ARB, with 135 mm lever arm length (measured perpendicular to torsional element). Fabricate from EN16T bright bar. Replace current bearing mounts with aluminium split bearing blocks.**
e) Set rear static ride height to 200 mm under the trailing arm mounting bracket.
f) **Fit two extra full length leaves in rear springs, same width and thickness as existing leaves.**
g) **Fit 105 mm long parallel Koni 8212 bump rubber in rear bump rubber cradles, set to 12 mm compression at static ride height. Make sliding guide tubes for bump rubbers.** (To make the 105 mm bump rubber, purchase 4 Koni bump rubbers part no 70.34.53.000.0 (55mm) mount on wooden mandrel and on lathe, use Stanley knife blade to cut off tapered portion and discard. This will leave a 30 mm long parallel section. To achieve the105 mm length specified, use 3 x 30 mm parallel lengths and cut the 4^{th} to 15 mm long, parallel.
h) Set front static camber to 2 degrees negative.
i) Set rear static camber to 0.6 degrees negative (if possible).
j) Fit ramp and plate LSD (consider Gripper) with 85 degree coast ramps, 45 degree drive ramps, 12 friction surfaces and 25 -30 LbFt (34-41 Nm) preload.
k) Dyno test, set and if necessary re-valve dampers in line with table below.
l) **Implement steering geometry modifications outlined in section 2.1, blue text to reduce bump steer, but first physically measure bump steer and DISCUSS.**
m) **Where possible, move weight rearwards and to the right.**
n) **Detail set up as below:**

DETAILED RECOMMENDATIONS (RACE SETUP):

	FRONT	REAR
Spring Rate	Current 140 Lbf/in per side Leaf Spring	124 Lbf/in leaf spring (Current spring with 2 extra full length leaves)
Ride Height	178 mm under chassis cross member 850 mm behind front axle CL.	200 mm under railing arm forward mount.
Static Camber	-2.0 Degrees	-0.6 Degrees (if possible)
Droop	Minimum 20 mm	Minimum 35 mm
Castor	5 Degrees (Fixed)	N/A
Toe**	0.2 Degrees OUT	0.25 Degrees IN (if possible)
ARB O/D	**24 mm (NEW)**	N/A
ARB I/D	**0 in (Solid)**	N/A
ARB Lever Arm*	**135 mm**	N/A
Dampers	SEE NOTES BELOW	
Tyre Pressures (starting point, refine through temperature)	41 psi HOT **(DUNLOP)** 36 psi HOT **(AVON 205/70)**	40 psi HOT **(DUNLOP)** 35 psi HOT **(AVON 205/70)**
Bump Rubber	Current Rubber hoop	KONI 8212 105 mm parallel
Packers (Damper Clearance @ SRH)	6 mm compression	12 mm compression at SRH

*** Measured perpendicular to the torsional element.**
**** When setting Toe, also check for F&R bump steer.**

To assist in spring length selection, please note that the static compression of the recommended springs, due to the weight of the car, are:

Front: 102 mm (Leaf spring only)
Rear: 159 mm (Leaf spring only)

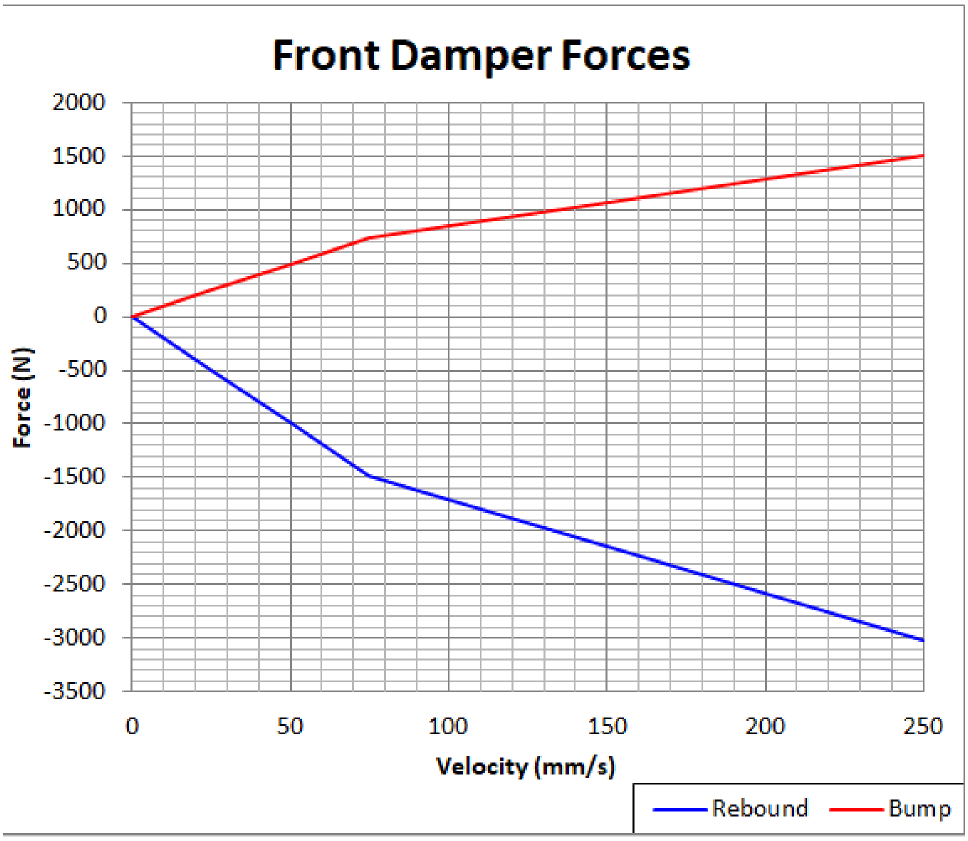
KEY PARAMETERS FOR REFERENCE ONLY (RACE SETUP):

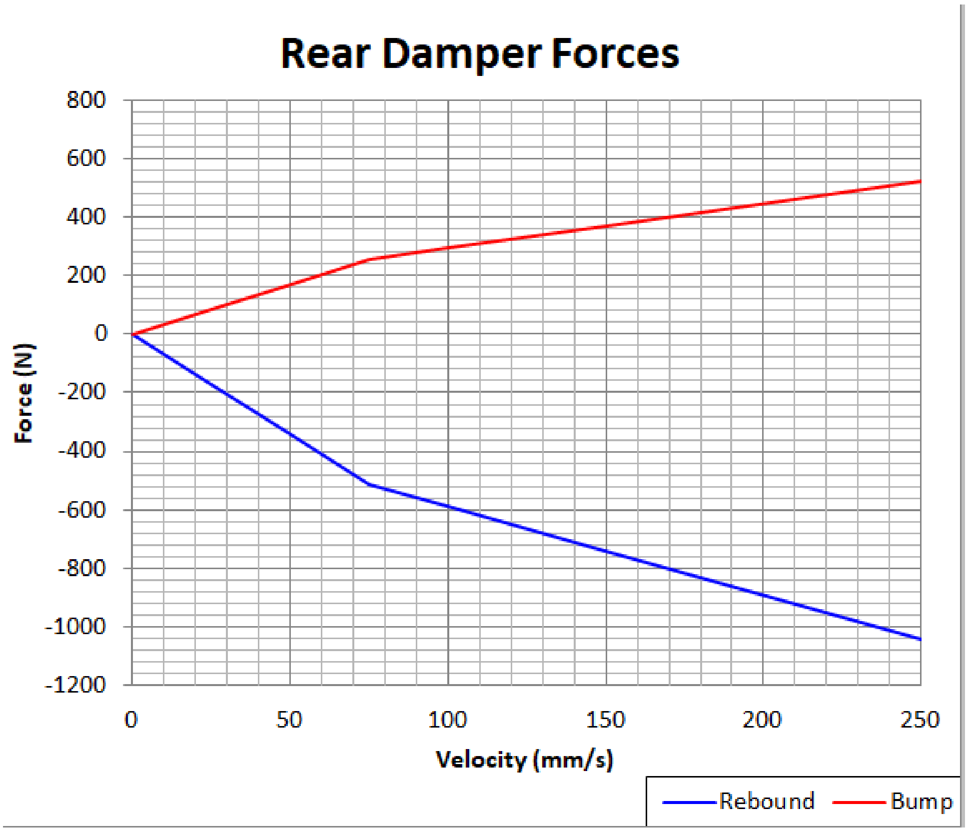
Car Weight incl. Driver	1151 Kg (2537 Lbs) inc. 75 Kg driver and 45 Litres fuel	
Unsprung Weight	Approx. 31 Kg Front, 42 Kg rear.	
	FRONT	**REAR**
Weight Distribution	49.5 %	50.5 %
Planned Spring Rates	140 Lbf/in (24.5 N/mm) Plus 650 Lbf/in (114 N/mm) bump rubber	124 Lbf/in (21.7 N/mm) leaf spring + 108 Lbf/in (19 N/mm) bump rubber cradle
Wheel/Spring Motion Ratio	1:1 (Bump rubber 1.957:1)	Bump - 1:1 Roll - 1.3817:1 Bump Rubber 1:1 bump, 2.197:1 Roll
Wheel/Damper Motion Ratio	1.089:1	Bump - 1.:1 Roll - 1.7133:1
Wheel Rates	256 Lbf/in (45 N/mm)	Bump - 231 Lbf/in (41 N/mm) Roll - 95 Lbf/in (16.6 N/mm)
Natural Frequencies	2.33 Hz	2.04 Hz
Wheel rate due to ARB	734 Lbf/in (129 N/mm)	N/A
Aerodynamic Downforce	Negligible	
Max Lateral 'g'	1.0 g	
Max Longitudinal 'g'	1.3 g braking from 130 mph	

NOTES RE DAMPERS (SEND TO DAMPER MANUFACTURER TO CHECK VALVING) (RACE SETUP):

Damper characteristics when set at 'middle' should be close to:

	FRONT	REAR
Rebound force at 25 mm/s shaft speed (Newtons)	480 N	170 N
Rebound force at 50 mm/s shaft speed (Newtons)	960 N	340 N
Rebound force at 75 mm/s shaft speed (Newtons)	1440 N	510 N
Rebound force at 100mm/s shaft speed (Newtons)	1640 N	580 N
Rebound force at 150mm/s shaft speed (Newtons)	2000 N	720 N
Rebound force at 250 mm/s shaft speed (Newtons)	2800 N	1000 N
Rebound to Bump Ratio	2.0	2.0
LS to HS Transition	75 mm/s	75 mm/s
Critical Damping Coefficient	14.95 Ns/mm	6.33 Ns/mm


Front Damper Forces
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
Force (N)
0
50
100
150
200
250
Velocity (mm/s)
Rebound
Bump


Rear Damper Forces
800
600
400
200
0
-200
-400
-600
-800
-1000
-1200
Force (N)
0
50
100
150
200
250
Velocity (mm/s)
Rebound
Bump

2.0 Suspension Geometry

See table below.

2.1 Front

Front suspension is by dual unequal length wishbones, a transverse leaf spring operated by the lower wishbone and Houdaille rotary / lever arm dampers operated by drop arms from the lower wishbones. A non-adjustable front anti- roll bar is fitted.

Geometry and kinematics are generally quite good with a near ground level roll centre, reasonable camber change with bump, but poor roll camber correction at only 11%.

Pitch geometry gives 10 % pro-dive under braking. This is a consequence of the trunnion based king pin system, which means that the wishbones must be tilted to achieve castor – 5 degrees in this case. While this is not ideal, nose dip can be controlled with careful front spring, bump rubber and gap selection.

We recommend lowering the front ride height by 12 mm by removing the 12 mm thick aluminium block above the leaf spring centre clamp. This generally improves geometry and increases roll camber correction to 20.3 %.

It was difficult to measure steering pivot heights precisely, but our theoretical analysis shows slight toe out on bump / roll understeer. This is a stable condition when cornering, but reduces precision. In this case it is not serious – much less severe than on the 250 SWB. Theory suggests that moving the track rod outer pivots upward by 6 mm or track rod inner pivots downward by 6 mm would correct the problem. It is essential to measure bump steer precisely before taking action. DISCUSS.

2.2 Rear

Rear suspension is by live axle, half-elliptical leaf springs on swinging hangers at both ends and Houdaille rotary / lever arm dampers. Twin radius rods per side provide longitudinal location, while lateral location is provided by the leaf springs solely.

Geometry is good, except for a high roll centre (332 mm at the recommended ride height) - however, in this case, this aids the handling balance of the car, reducing understeer.

There is not a rear anti roll bar, nor is there provision for one - and regulations do not permit us to fit one.

Roll camber compensation is excellent at 100%.

Geometry and Kinematics Summary:

	FRONT	REAR
Ride Height (mm)	178 mm under cross member 850 mm behind front axle CL	200 mm under forward trailing arm mount
Camber change per 10 mm bump (Degrees)	-0.315	0
Deflection (Track Change) per 10 mm bump (mm)	-0.718	0
Virtual Swing Axle Length (mm)	3238	Infinite
Roll Centre Height (mm)	-7	332
Roll Centre movement with 10mm bump / droop (mm)	3	5
Anti-Dive/Squat Coefficient	10% pro-dive	negligible
King Pin Inclination (Degrees)	9.3 degrees	N/A
Scrub Radius (mm)	74 mm	N/A
Roll Camber Correction	20.3 %	100% (excl. tyre compression)

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3.0 Spring / Damper and Anti Roll Bar Actuation & Motion Ratios

3.1 Front

Front wheel to leaf spring motion ratio is very good at 1:1.

Front wheel to damper motion ratio is good at 1.4438:1.

The current 140 Lbf/in per side (24.5 N/mm) front springs give a wheel rate of 140 Lbf/in (24.5 N/mm) and a natural frequency of 1.56 Hz. This alone would be too soft.

- However, shaped, hollowed rubber bump rubbers are in use. We measured bump rubber stiffness in a press, giving a rate of 650 Lbf/in (114 N/mm) for the first 22mm travel, rising to 1485 Lbf/in (260 N/mm) for the next 5 mm travel, then stiffening sharply. Wheel to bump rubber motion ratio is 1.957:1, so the bump rubber gives a wheel rate of 170 Lbf/in (30 N/mm) for 43 mm wheel travel. This, together with the leaf spring would give a wheel rate of 310 Lbf/in (54.3 N/mm) and a natural frequency 2.33 Hertz, if the bump rubber was only slightly compressed. This would be ideal for race events, but a little stiff for rallies. Unfortunately, as currently configured, the bump rubber is compressed more than is ideal at static ride height, moving into the rising rate area. Therefore the car is currently stiffer than ideal in bump.

We recommend retaining the existing front springs and bump rubbers, but modifying the bump rubber reaction plates on the wishbones to give 6 mm bump rubber compression at static ride height. This gives a wheel rate of 310 Lbf/in (54.3 N/mm) and a natural frequency of 2.33 Hz.

Wheel to front ARB motion ratio is OK at 1.4438:1.

The current 0.787 in (20 mm) OD solid front ARB gives an effective wheel rate in roll due to the ARB of 352 Lbf/in (62 N/mm) with the current 135 mm fixed lever arms (measured perpendicular to the torsional element). This is too soft.

We recommend fitting a 24 mm OD solid front ARB, made from EN16T bar, with the current 135 mm lever arm length (measured perpendicular to the torsional section). This gives an effective wheel rate in roll due to the ARB of 734 Lbf/in (129 N/mm).

Note: We will need to source a significantly softer front bump rubber (230 Lbf/in) with longer travel for rallies. DISCUSS.

3.2 Rear

Rear wheel to spring motion ratio is excellent at 1:1 in bump, and 1.3817:1 in roll.

Rear wheel to damper motion ratio is OK at 1:1 in bump and 1.7133:1 in roll.

We calculate that current leaf springs have a rate of 87 Lbf/in (15 N/mm), which gives a wheel rate of 87 Lbf/in (15 N/mm) in bump, 46 Lbf/in in roll) and a natural frequency of 1.125Hz. This is much too soft - again, even softer than ideal for road use.

The team has fitted excellent bump rubber reaction cradles above the rear axle. The bump rubbers currently fitted were measured in the press to give a rate of 542 Lbf/in (95 N/mm) for 20 mm travel. This is too stiff – and the current 32 mm clearance at SRH is too large.

We recommend fitting:

1) **Two extra leaves, full length, to the rear leaf springs. This increases the rate of the spring to 124 Lbf/in (21.7 N/mm)**

2) **A 105 mm long Koni 8212 parallel bump rubber in each rear bump rubber cradle, set with 12 mm compression at static ride height. A guide arrangement for the bump rubbers will be needed.**

This arrangement gives a wheel rate in bump of 231 Lbf/in (40.5 N/mm), 87 Lbf/in in roll (15.25 N/mm in roll) and a natural frequency of 2.04 Hz.

This allows handling balance to be adjusted by addition or subtraction of packers in the rear bump rubber cradles.

4.0 Braking Analysis

This analysis simulates ‘on the limit’ braking from high speed (applying aerodynamic downforce if appropriate), assessing rake/pitch changes and ride height changes with varying spring rates/wheel rates.

The **recommended** springs, bump rubbers, packer gaps and ride heights give:

Static Rake	0.56 degrees
Dynamic Rake under braking	2.31 degrees
Nose ‘dip’ under braking (incl. tyre compression)	32 mm

5.0 Cornering Analysis

5.1 Power Off / Apex

This analysis looks at the car at the turn – in to apex period, with power off (or application of a little power to overcome drag).

As currently configured, total front roll stiffness is less than ideal, but wheel rate in bump is higher than ideal. Balance is reasonable, but front tyre efficiency is compromised by contact patch load variation and positive camber induced as the car roll to 2.4 degrees.
The recommended springs, ARB and damper settings give a more precise, stable turn-in with much improved transient response. The car gives slight safe understeer at the apex, and roll angle is reduced from 2.4 degrees to 1.7 degrees (incl. tyre compression), improving tyre efficiency.

5.2 Power On / Corner Exit

This analysis looks at the car under power/acceleration from corner apex, looking at high and low speed corners, in 2nd through 5th gears. The analysis includes the effects of tyre characteristics, load transfer, traction ellipse and traction vectors.

The recommended springs, ARB and setup give good traction and balance in the corner exit phase, giving the following characteristics:

a) Power-oversteer under full throttle in 2nd gear corners. Neutral balance with 162 bhp (79% throttle) applied.
b) Moderate, safe understeer under full throttle in 3rd and 4th gear corners.

6.0 Aerodynamics

The car does not generate any downforce – slight lift probable.

We estimate a drag coefficient (C_d) of 0.45 and frontal area of 21 Sq. Ft.
Estimated GSD C_{DA} = 0.011
Estimated GSD C_{LA} = 0

7.0 Engine / Transmission / Tyres

Tyres are Dunlop CR65, 204 compound, 'L'section. Sizes are:

Front : 6.00 L 15

Rear : 6.00 L 15

Peak coefficient of friction (μ) estimated at 1.48.

At some events, particularly Tour Auto, Avon CR6ZZ tyres may be used.
Sizes probably 205/70-R15 front and rear.

The table below gives tyre spring rates for the DUNLOP tyres at a range of pressures, predicted by our software tyre model:

FRONT TYRES

Tyre Pressure psi (HOT)	Front Tyre Spring Rate Lbf/in
37	1497
39	1622
41	1749
43	1876
45	2005

REAR TYRES

Tyre Pressure psi (HOT)	Rear Tyre Spring Rate Lbf/in
36	1420
38	1544
40	1669
42	1795
44	1923

The engine is a 2.7 Litre SOHC 24 valve Ferrari V12, producing 205 bhp at 7000 rpm. Max revs 7500 rpm.

Transmission is a Ferrari 4-speed, with an ‘add on’ overdrive 5th which is not used in race events, but is used on road sections in rally events.

The current LSD is a Cam and Pawl. These are rarely used today. We recommend fitting a Ramp and Plate LSD, with **85 degree coast and 45 degree drive ramp angles, 12 friction surfaces and 25-30 LbFt (34 - 41 Nm) preload.**

CWP: 7:32

Current gear ratio set:

1st	2.53
2nd	1.7
3rd	1.256
4th	1

8.0 Wet Setup

- Set rear dampers approx. 30% softer.
- Remove 15 mm of packers from the rear bump rubber stack.

9.0 Rally Setup – Avon CR6 ZZ tyres (Net Changes)

- **Soften damping by 20% front and rear.**
- **Remove 20 mm packers from rear dampers.**
- Set front static camber to 2.25 degrees negative.
- Tyre pressures (Avon 205 / 70 / R15): FRONT – 36 psi (HOT)
REAR - 35 psi (HOT)

10.0 Cam and Pawl LSD – Implications

We believe that the car is currently fitted with a Cam & Pawl differential. These are rarely used today, for very good reasons. They are 'free' when no power is applied, so do not contribute to braking stability. As soon as power is applied, the differential becomes a solid, fully locked 'spool'. This causes severe power understeer. In order to overcome this, cars were often set up with a very stiff rear ARB, soft front ARB and 10 degrees castor, all designed to unload the inside rear wheel to allow the car to turn. Application of power caused the outside rear wheel drive to 'rotate' the car. This only worked well if the driver adopted a 'pitch and power' style. Neither set up nor style was very efficient. Denny Hulme was a master of the 'pitch & power 'style in Can Am Mclaren M8s. A further problem with the Cam & Pawl differential is rapid pawl (chiclet) wear. To function correctly, they should be serviced (Pawls replaced) at 400 mile intervals.

Our clients are sometimes reluctant to pay for the change to a ramp and plate LSD. This is a false economy. The ramp and plate LSD gives an improvement of over 0.8 secs / lap at Donington National. The cost (£1100 - £2500) is comparable to two sets of tyres – and the performance improvement is similar – but PERMANENT. Further, maintenance costs are reduced. Retaining a Cam & Pawl LSD does not make sense in economic terms or performance terms.

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Global Sports Development Ltd and Sports Media Brokerage Ltd

Race Car Vehicle Dynamics Analysis Service

Terms and Conditions of Service

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