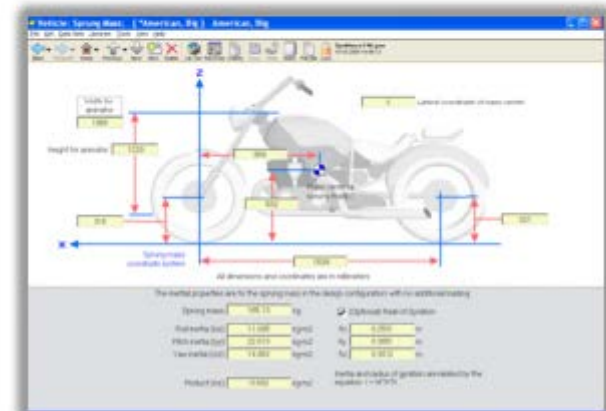


Vehicle Dynamics and Control

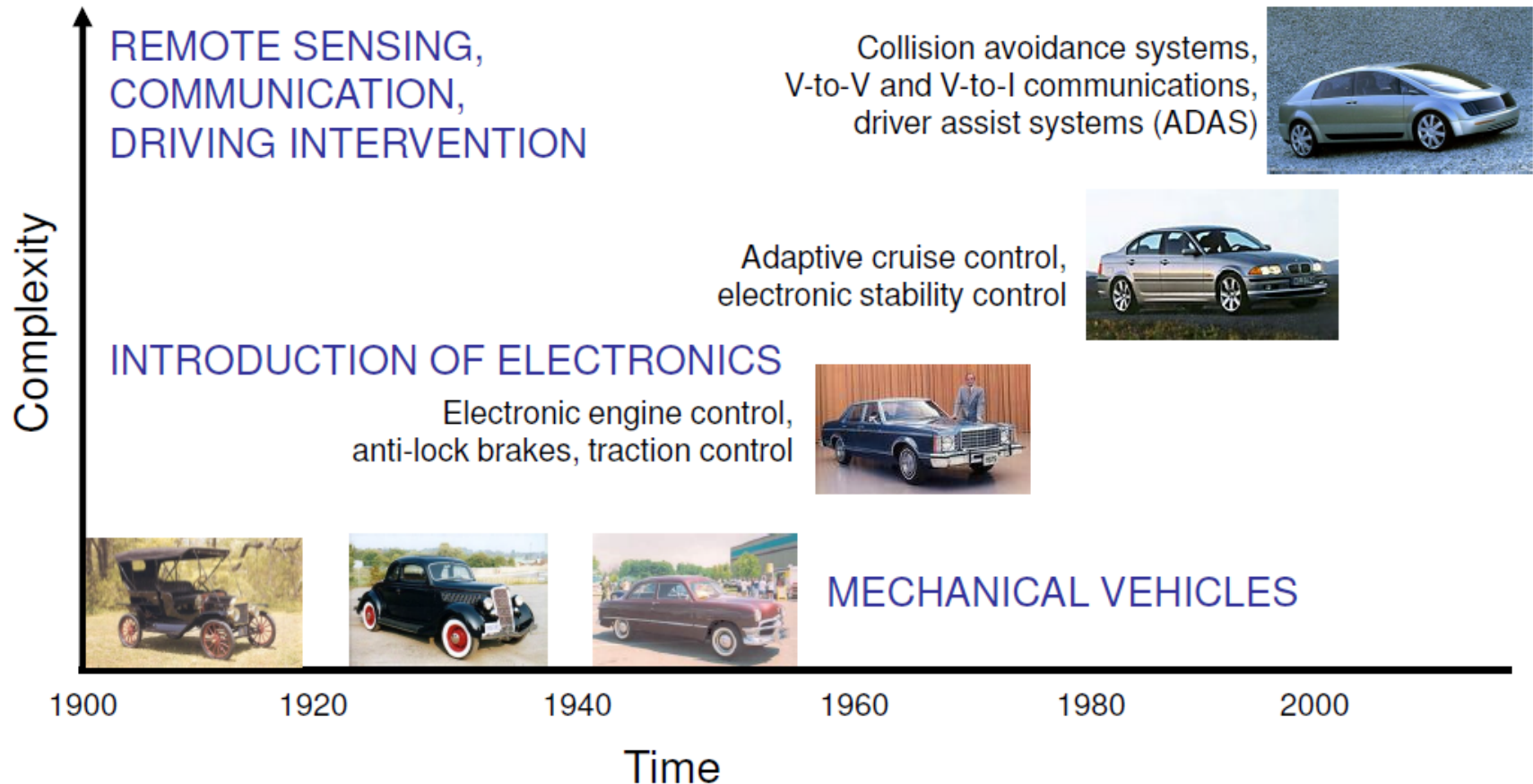
T. D Gillespie Phd

M Sandford

Overview of Current Vehicle Dynamics



Evolution of the Automobile



Mechanical complexity has grown exponentially
The first cars had about 2,000 parts
Modern cars have about 14,000 parts

1966 Mustang



2003 Mustang

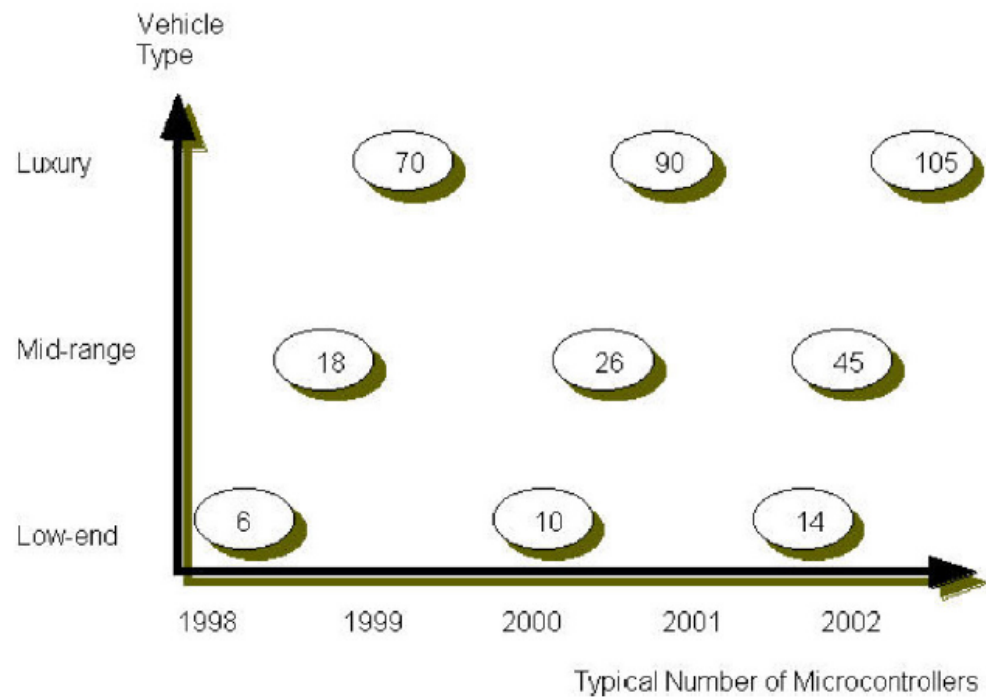


Electronics augment
Mechanical systems

- Sensing
- Computing
- Controlling

The result is an
Increase in ECUs
The functions of
Multiple ECUs
need coordinating
Many Influence
vehicle dynamic
behaviour

Growth in Microcontroller Use

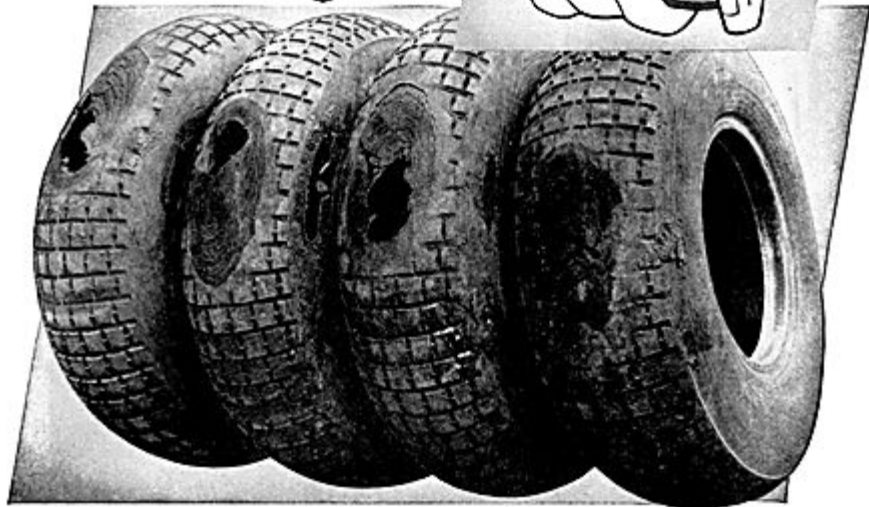


ABS The Paradigm Shift

- Pre ABS control paradigm
 - Brake force apply in accordance with brake pedal force
- Post ABS control paradigm
 - Brake force may be reduced during braking
 - There are times when the controller knows better than the driver
 - The controller can control more things at once.

Why Have ABS ?

HERE'S
HOW TO STOP
THIS



Excessive braking can cause a runway skid that will wreck even first class aero tyres in a few seconds. But tyre scrubbing need never happen! The Maxaret Anti-skid Unit weighs only 47 lb., and completely eliminates the danger of skidding without making any extra demands on aircraft services. Even if the wheels bounce clear of the runway after the brakes are applied, brake pressure is immediately released until ground contact is regained.

DUNLOP

MAXARET
ANTI-SKID UNITS

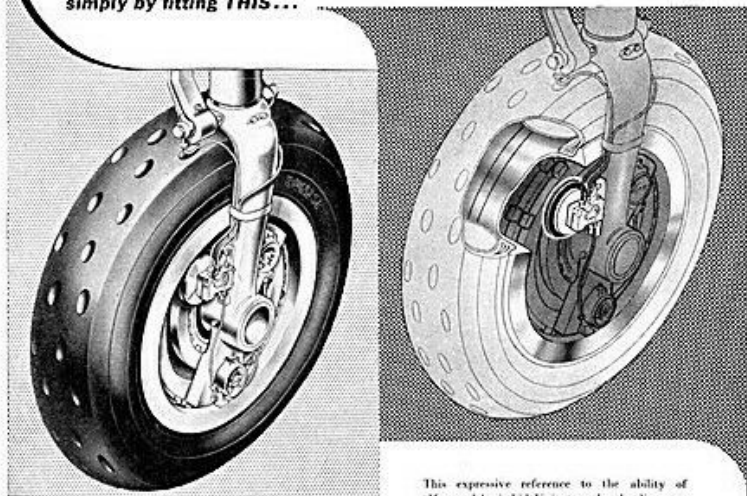
DUNLOP RUBBER COMPANY LIMITED (AVIATION DIVISION) • FOLESHILL • COVENTRY

50/5122

TEST PILOT REPORTS:

"2000-yd runway increased at least 800 yards!"

simply by fitting THIS...



This expressive reference to the ability of 'Maxaret' Anti-skid Units to *reduce* landing runs—and so, in effect, to *increase* runs as length—is extracted from one of many enthusiastic Flight Test Reports. The facts and figures available show that the simple, small and compact Maxaret shortens braking distances up to 30%, prevents wheel skidding and tyre 'scrubbing' damage, prolongs tyre life, gives added safety in emergency and allows maximum braking at all times—with pilot control right up to skidding-point. The unit is standard—fits, without adjustment, all sizes of wheel—and makes no additional demands on aircraft services. Full details are obtainable from the Dunlop Aviation Division.

Now being fitted to Britain's 'super-priority' aircraft



TYRES • WHEELS & BRAKES
INCORPORATING...

'MAXARET' ANTI-SKID UNITS

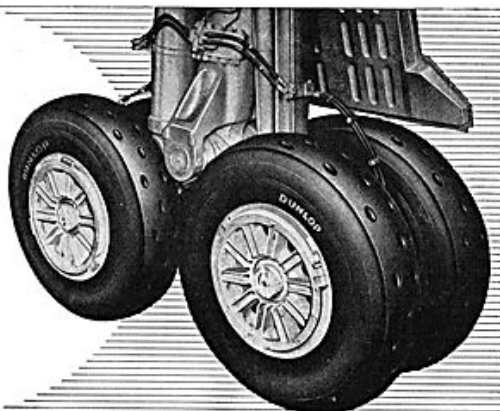
DUNLOP RUBBER COMPANY LIMITED • (AVIATION DIVISION) • FOLESHILL • COVENTRY

Landing runs

reduced

by nearly

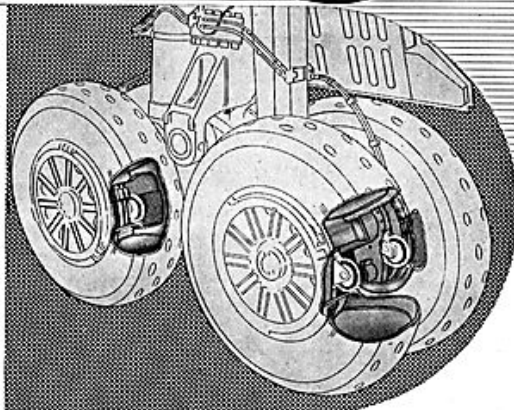
one-third



*simply by
fitting THIS*



Flight Test Reports on the 'Maxaret' Anti-skid unit show clearly that this remarkable Dunlop device will cut up to 30% off braking distance. Simple, small and compact, the 'Maxaret' keeps maximum braking capacity constantly available yet leaves control in the hands of the pilot right up to skidding-point. It prevents wheel skidding and tyre scrubbing damage, prolongs tyre life and gives added security in an emergency. The unit weighs under 5 lb., fits without adjustment any size of wheel and makes no additional demands on aircraft services. Full details are obtainable from the Dunlop Aviation Division.



DUNLOP

TYRES • WHEELS AND BRAKES
INCORPORATING

*Now being fitted to
Britain's 'super-priority' aircraft*

'MAXARET' ANTI-SKID UNITS

DUNLOP RUBBER COMPANY LIMITED • (AVIATION DIVISION) • FOLESHILL • COVENTRY

Jensen FF – 7 litre 1968 (Dunlop Maxaret ABS (aviation))



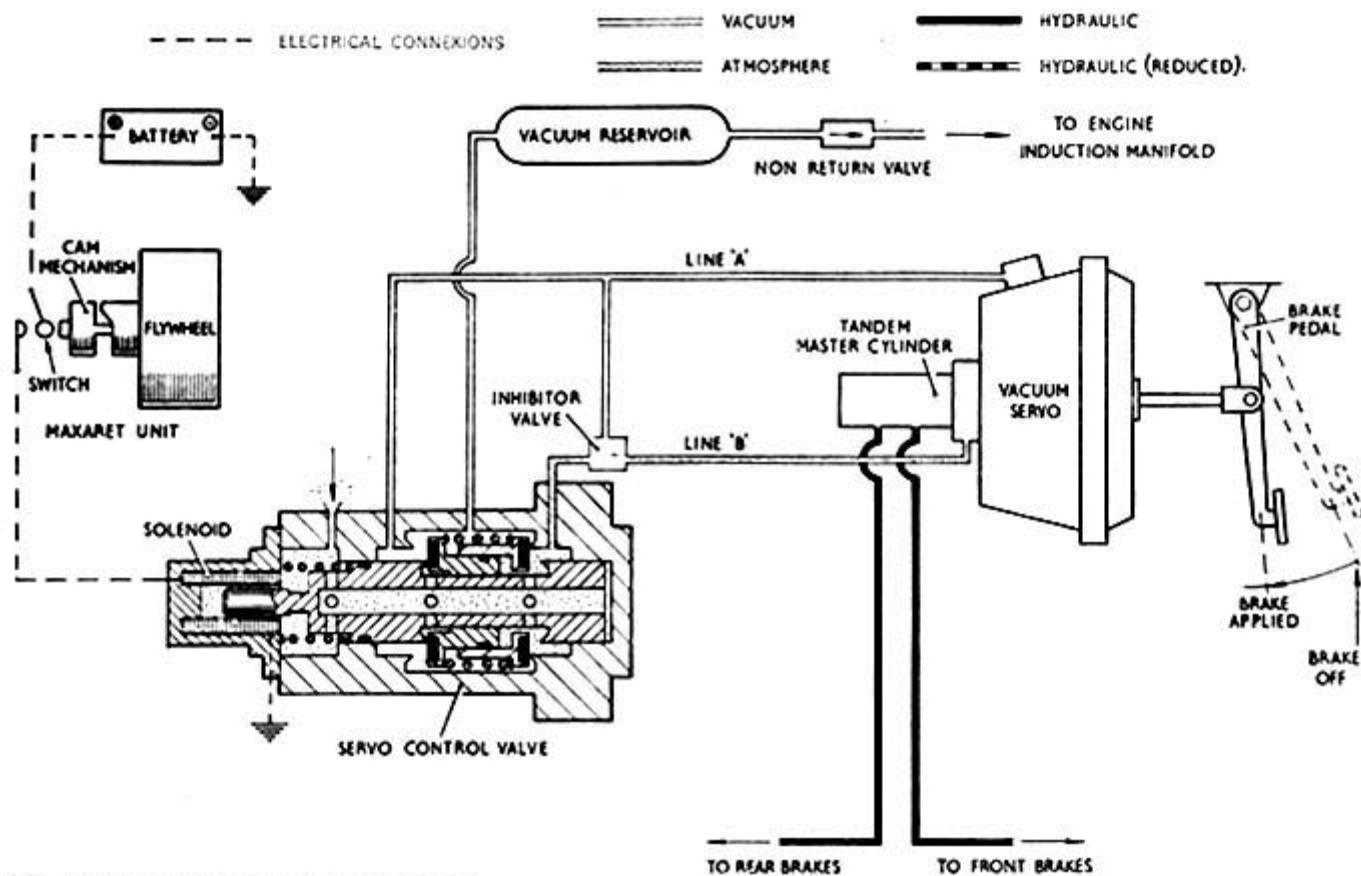
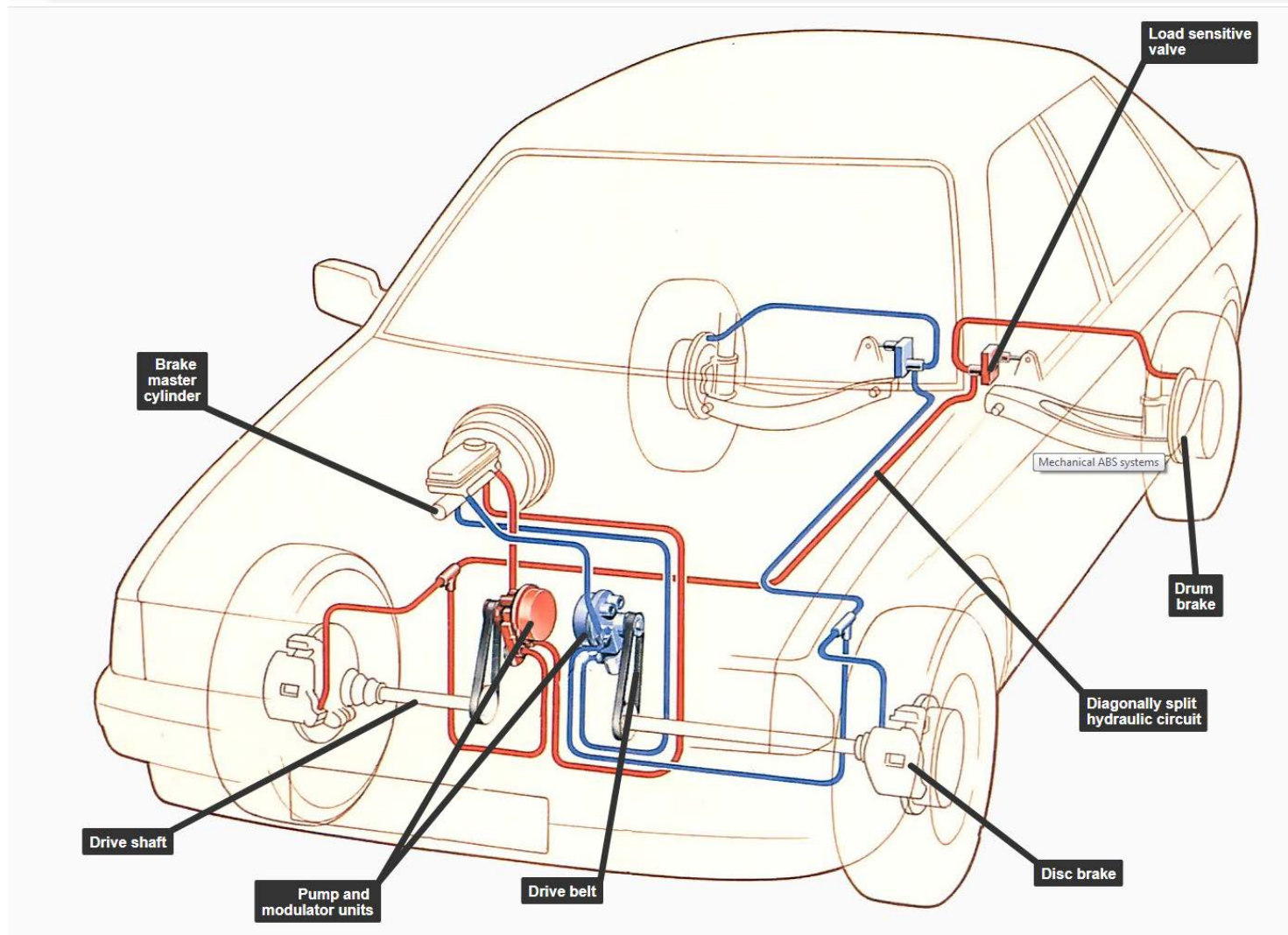
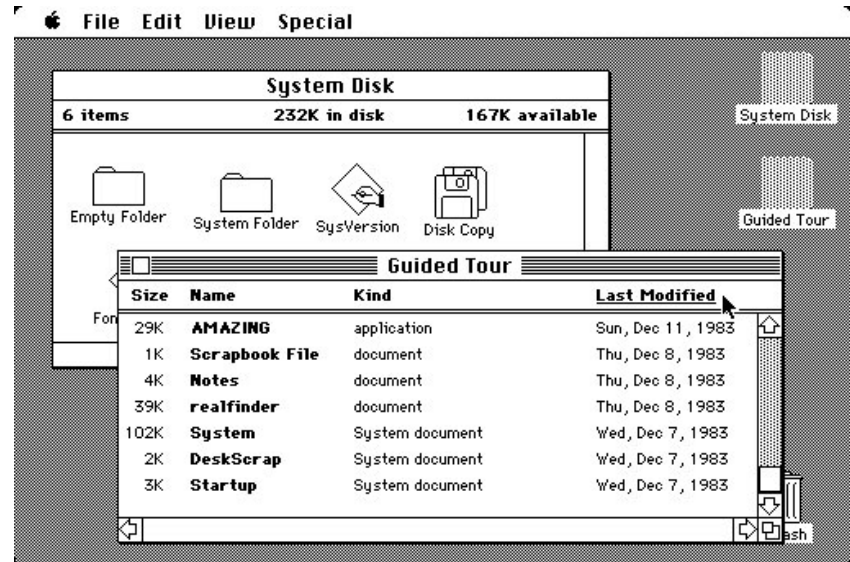


Fig. 1 System during normal non-skid braking.

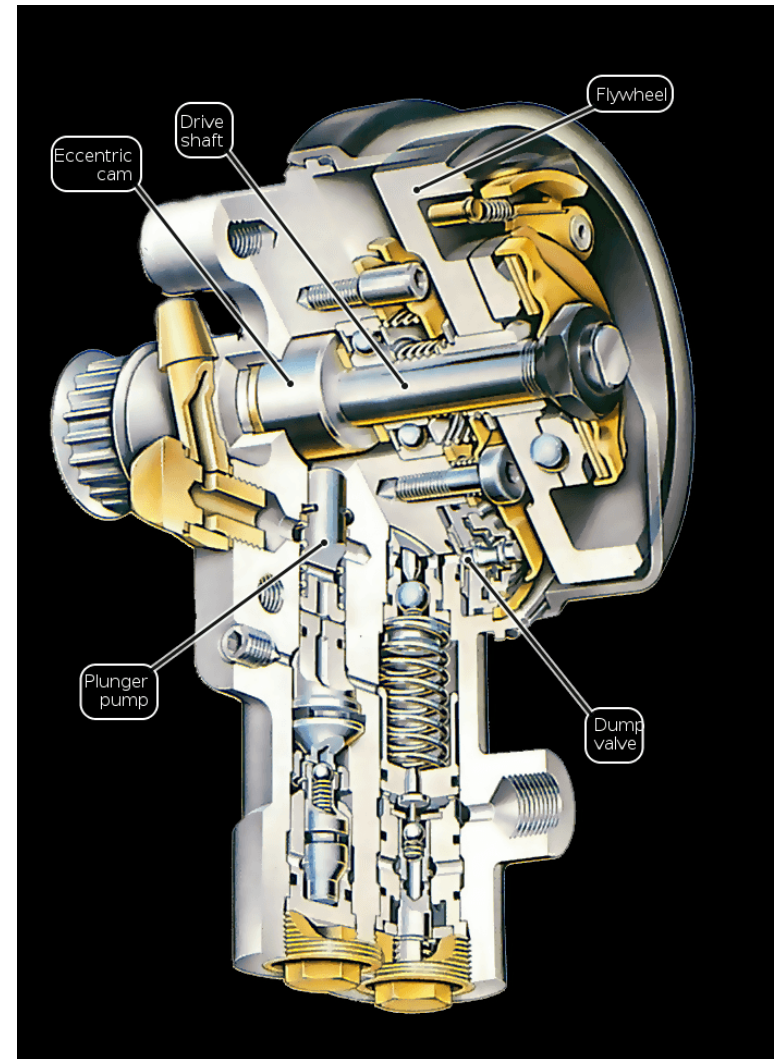
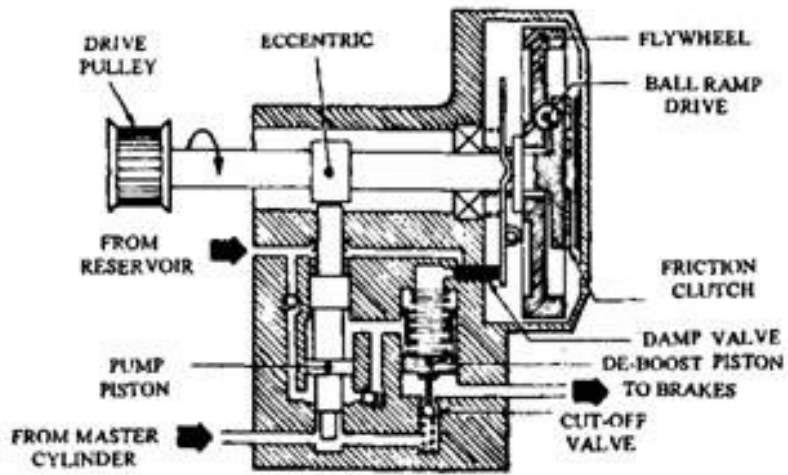
Lucas Stop Control System (SCS) 1984



Macintosh HISTORY



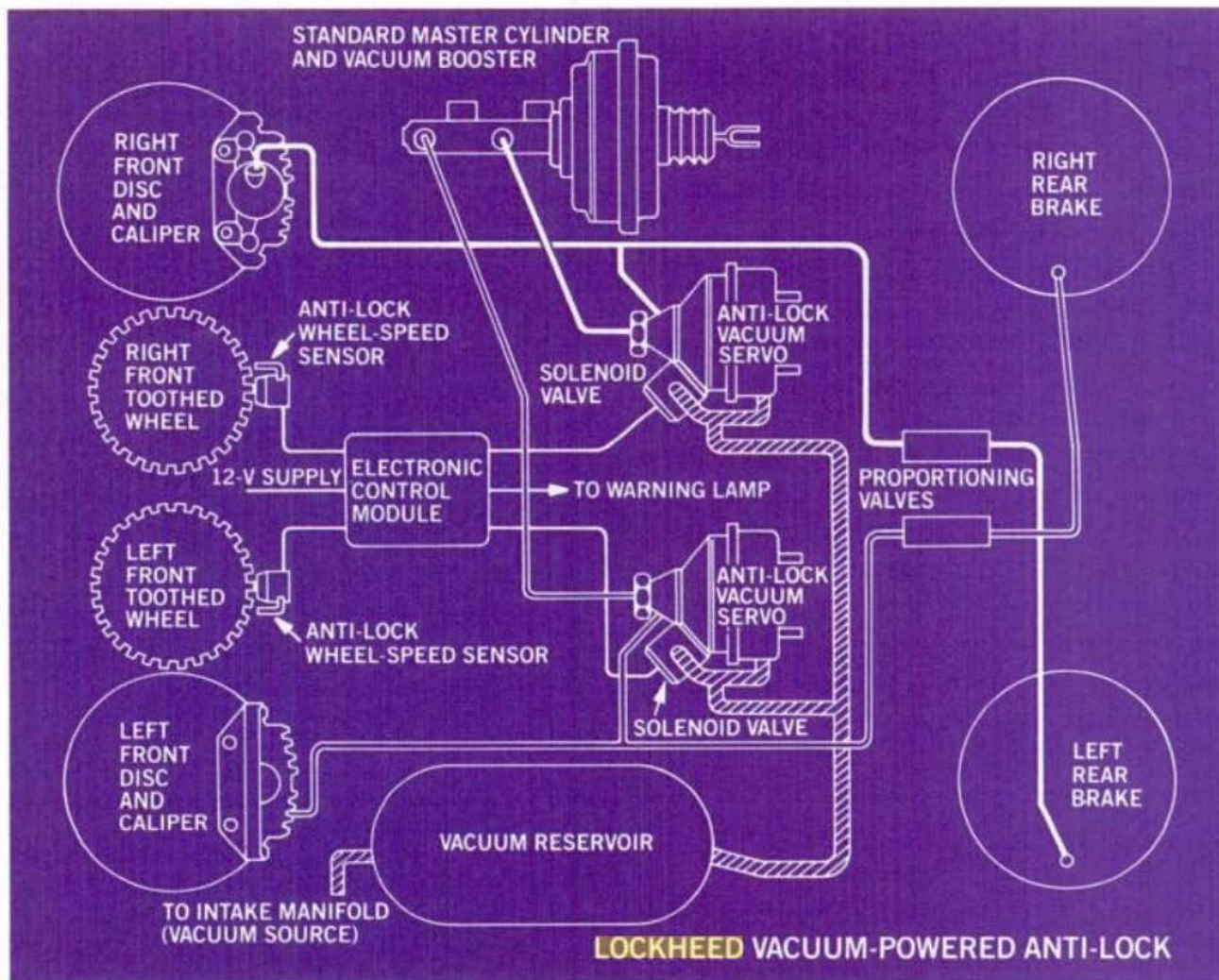
Apple Mac launch 1984.
256kb memory (£2000)
(Ford Fiesta £2500)





No-skid stops at bargain prices are the promise of a new anti-lock braking

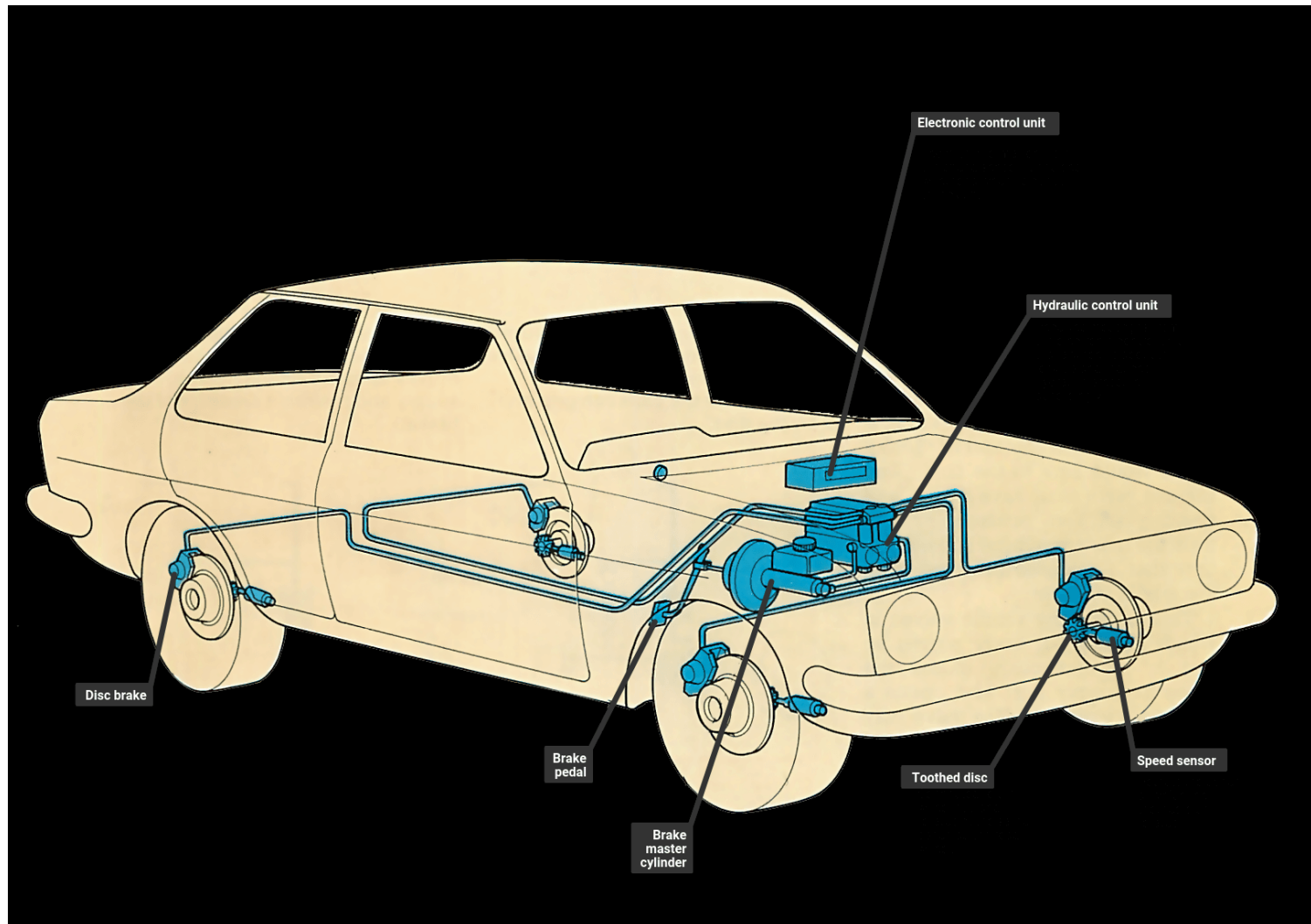
Popular Science Oct 1987



AP Lockheed – AntiLok System (Vacuum powered)

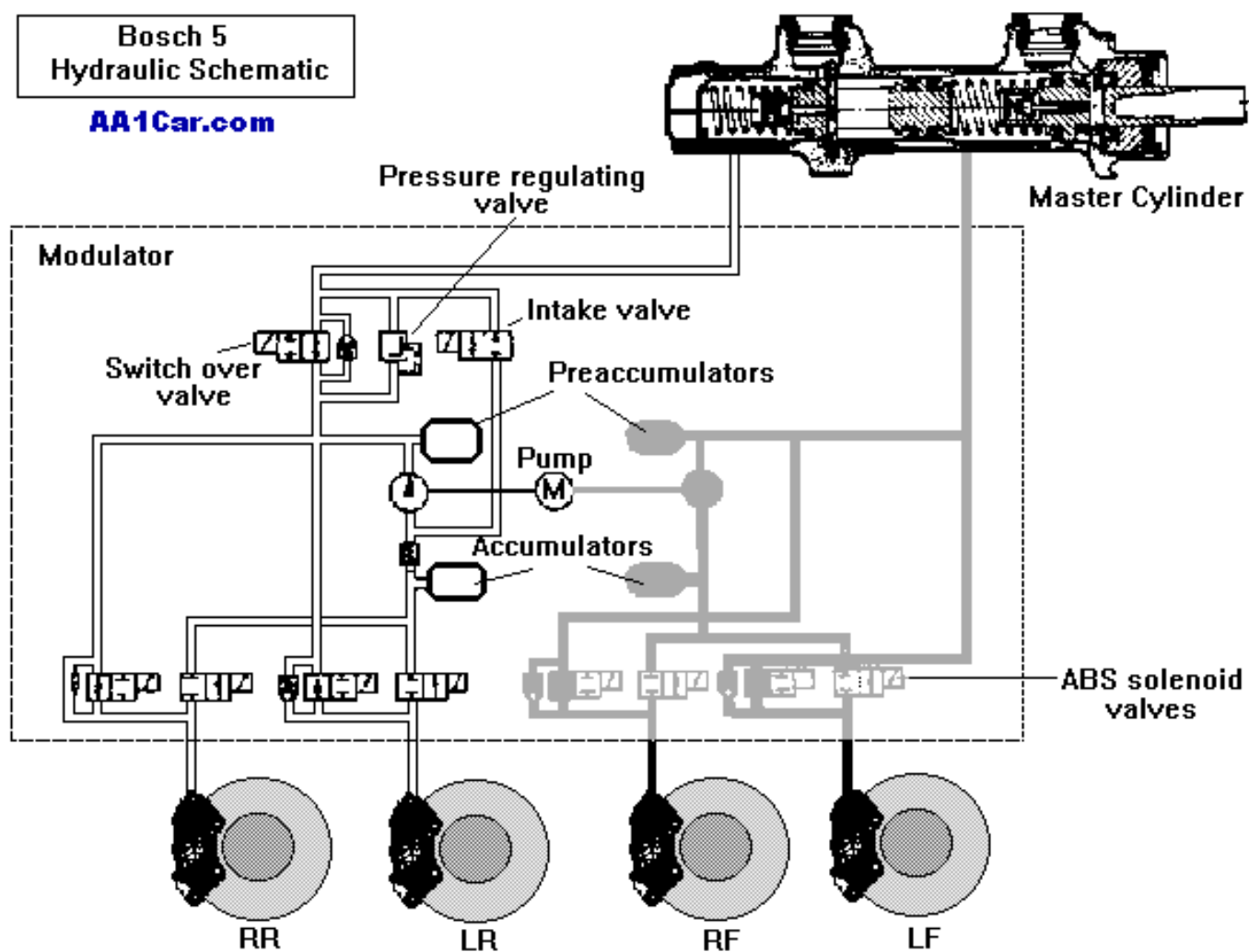
Bosch ABS

<https://youtu.be/mKiTAcXK6M4>



Bosch 5
Hydraulic Schematic

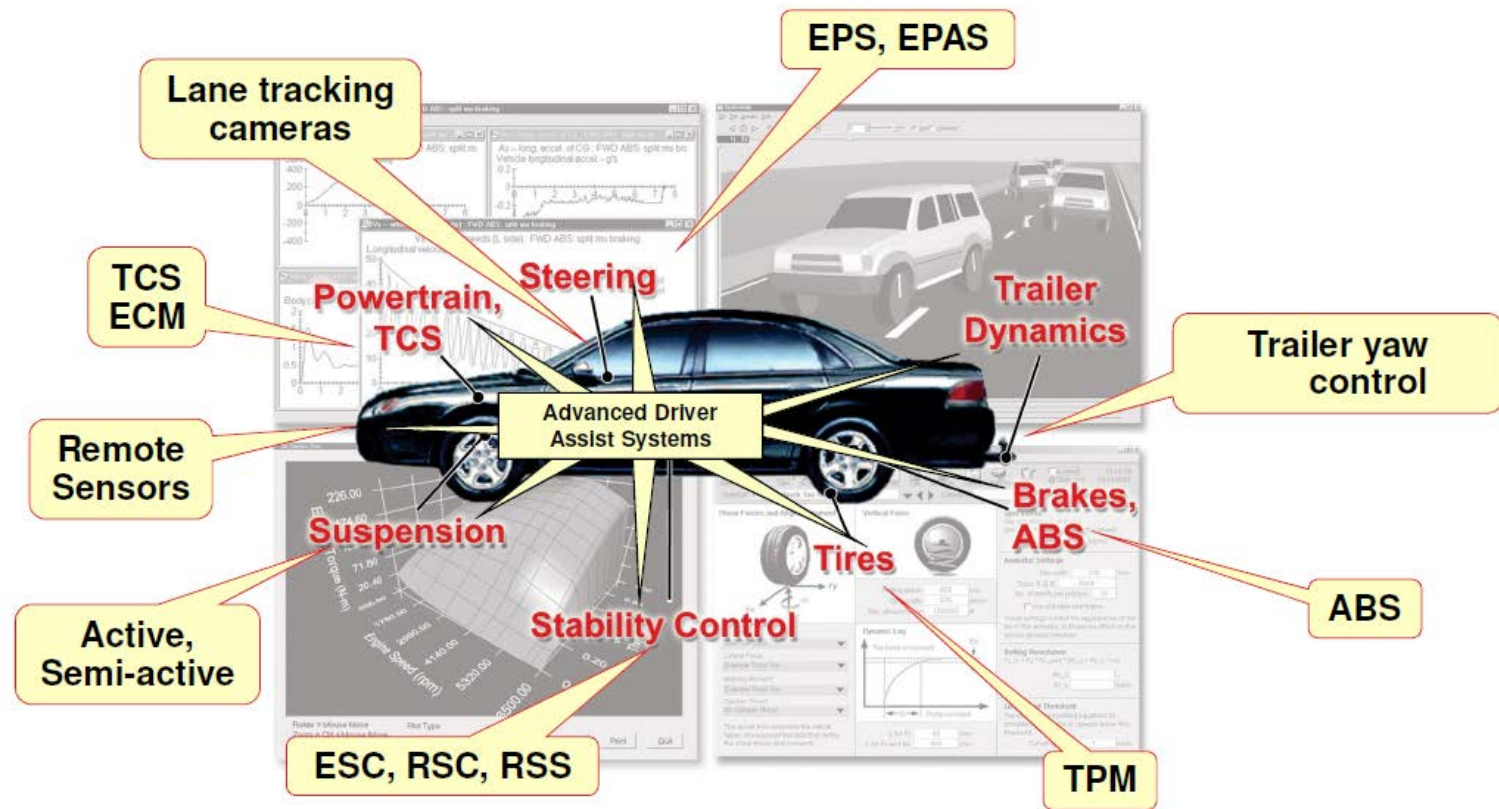
AA1Car.com



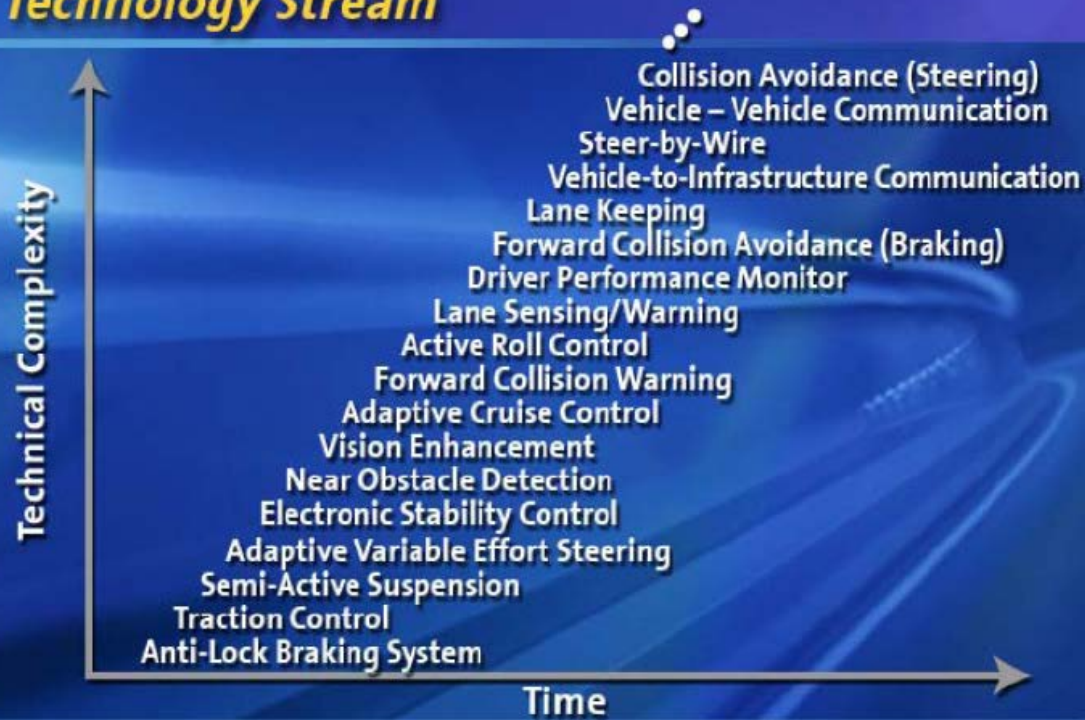
ABS The Paradigm Shift

- The ability to sense, compute and actuate means that we can change the behaviour of the car to suit the driving conditions.
- This places responsibility on the automotive systems engineers.
 - Design for **known** driving conditions
 - Have tolerance for the **unknown**

Electronics Influence All Vehicle Dynamics

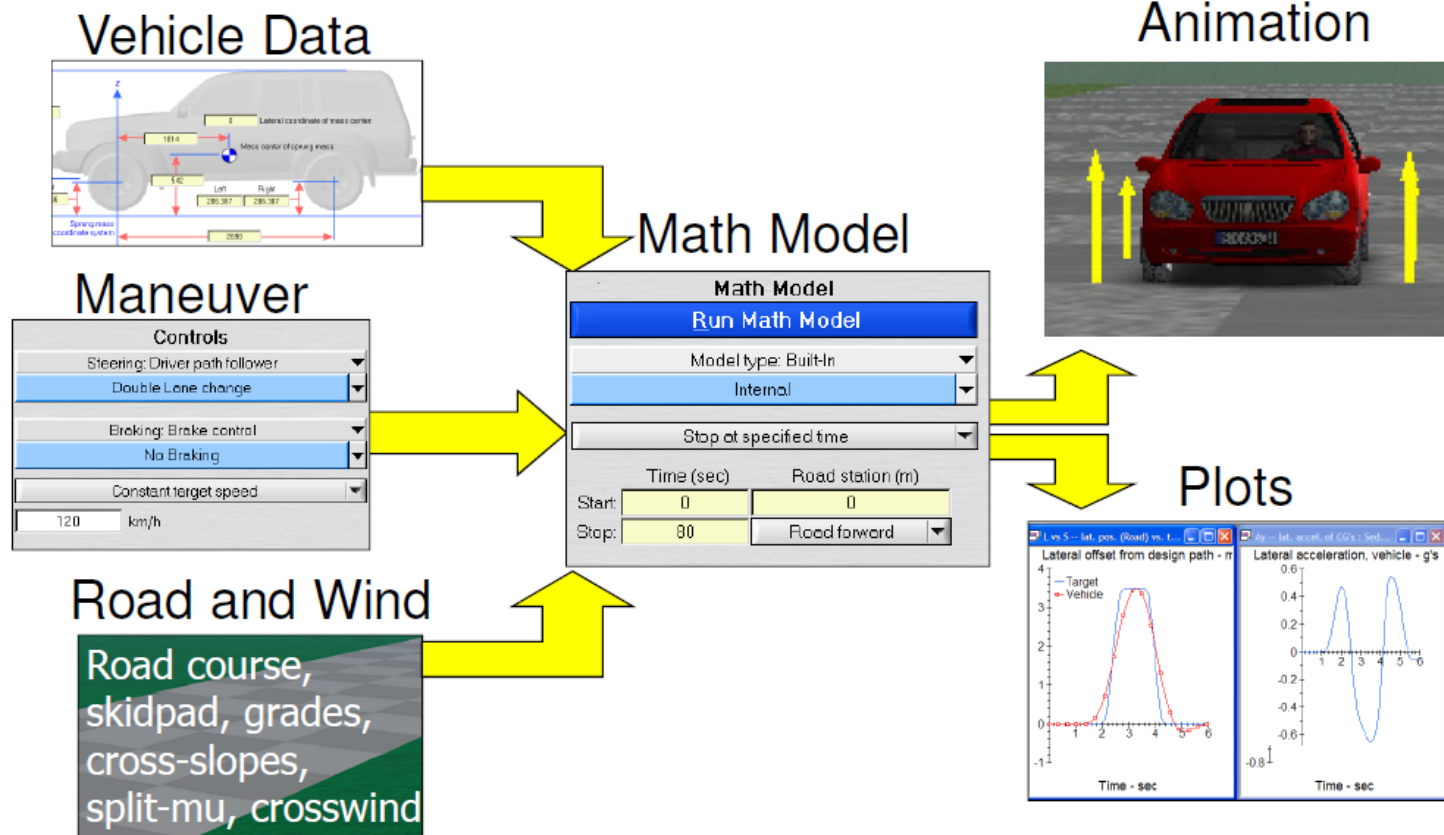


Advanced Safety Technology Stream



Larry Burns, General Motors, "Automotive Trends and Opportunities"

Vehicle Dynamics Simulation



**Product
Launch**



Marketing Tools -
Animations, driving
simulators

**Vehicle
Testing**



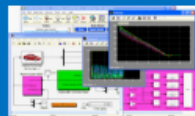
Proving Ground Optimization
Regulatory certification

**Component
Testing**



Test with Car*Sim* and
Hardware in the Loop (HIL)

**Controls
Development**



Test with Car*Sim* and other
Software in the Loop (SIL)

**System
Definition**



Simulate with Car*Sim*
Answers to "What if...?"

**Vehicle
Definition**



Vehicle Requirements,
Capabilities, and Capacities

Aftermarket



Testing and Simulation

Stand alone

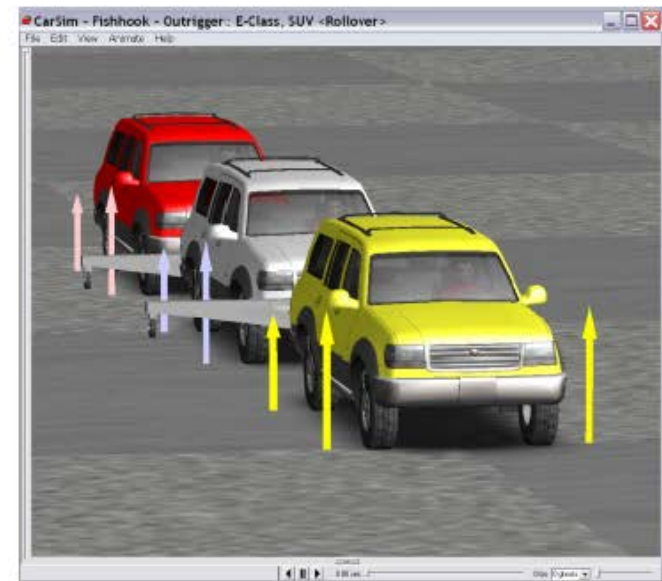
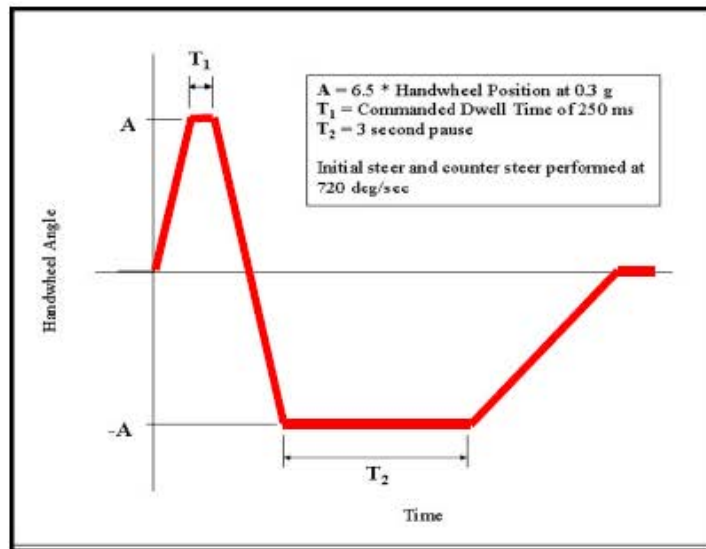
Software runs simulation as fast as possible.

Software in the loop

Simulation incorporates control software afap

Hardware in the loop

eg ECUs, actuators etc. Runs real time



Fishhook manouvre

SIL example – Simulink controller

Run Control with Simulink

ABS Controller (CS7)

Live animation is available with a driving simulator license

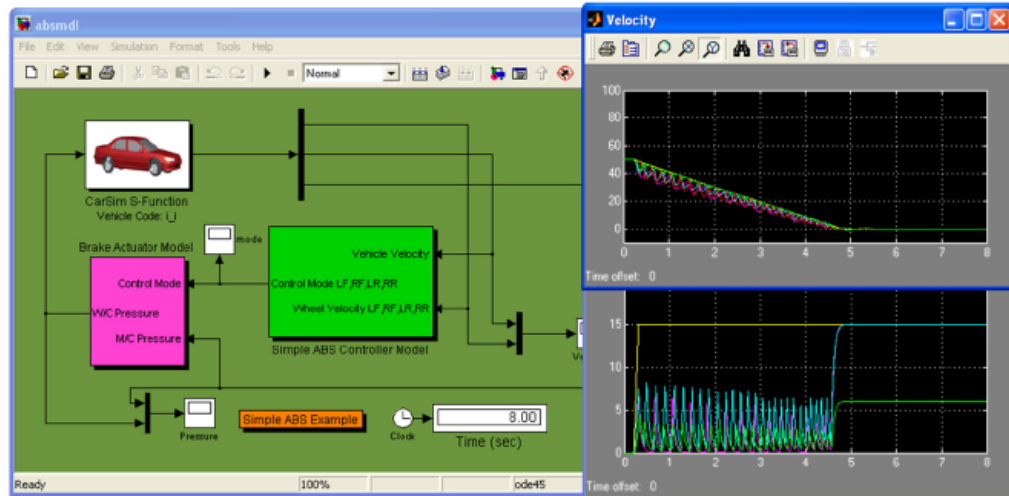
Stop run at specified time

	Time (sec)	Road station (m)
Start:	0	0
Stop:	8	Road forward

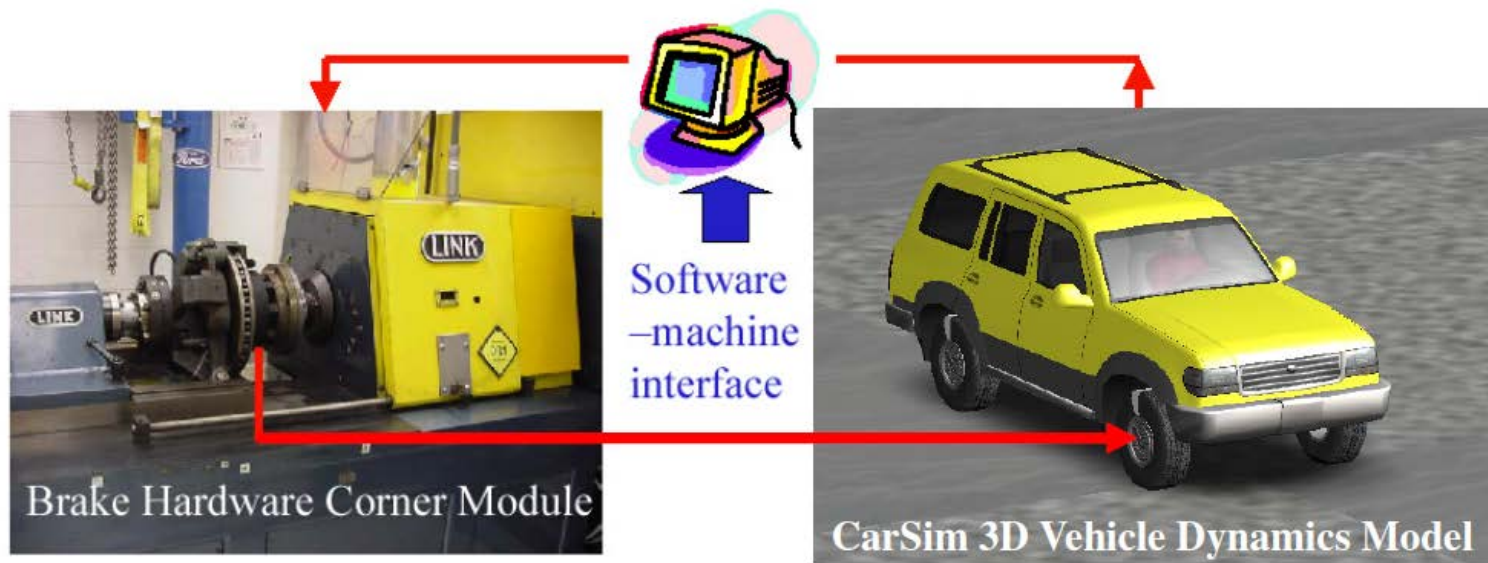
Output variables: Write Channels

Basic Outputs

	Time step (sec)	Freq. (Hz)
Math model:	0.001	1000
Output file:	0.025	40



HIL example – Braking system

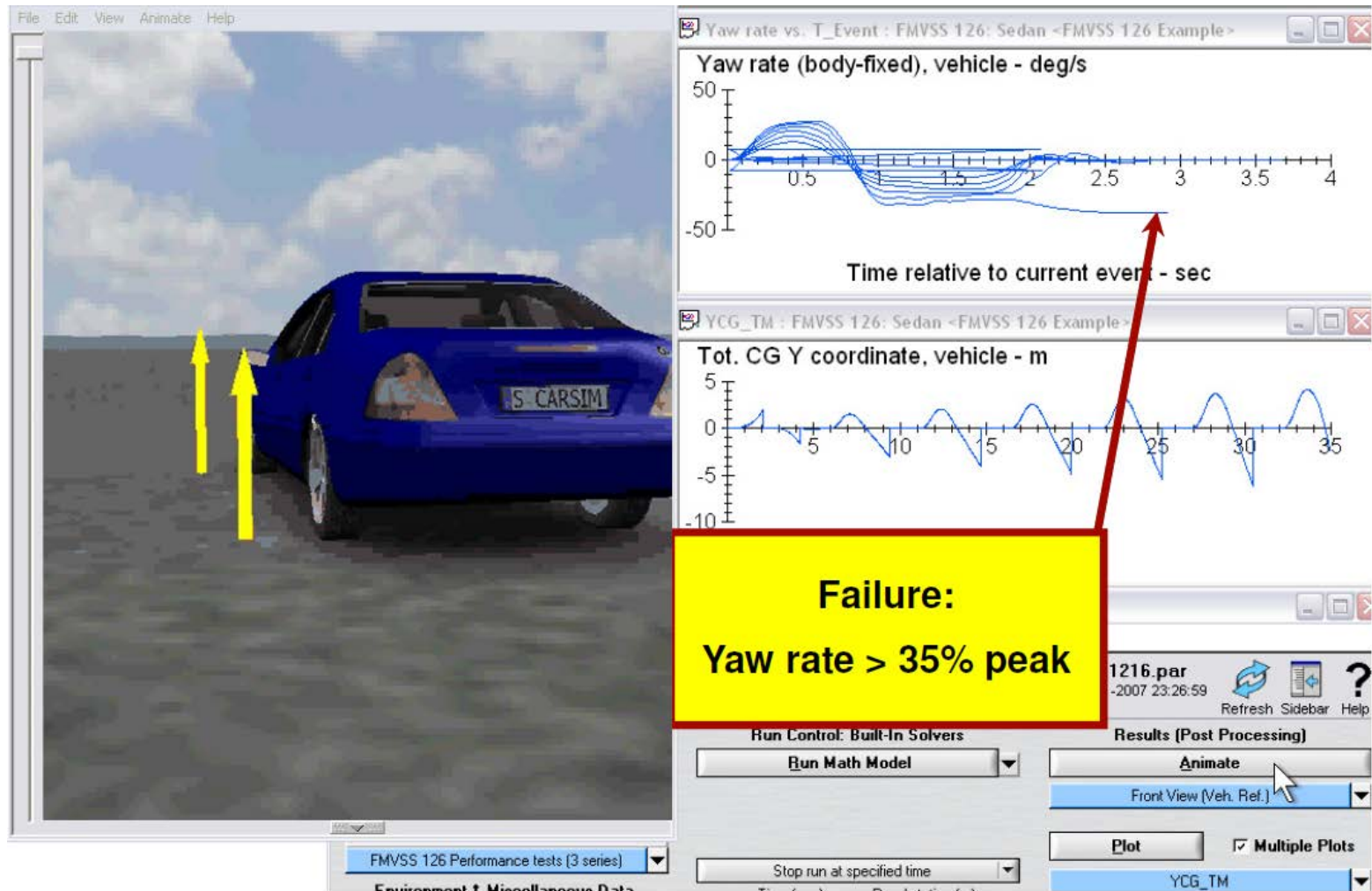


Brake pad friction hard to model

Brakes on dynamometer

Model interacts with brakes for a variety of manoeuvres

Moose test



VSC I 2002 - 2004



DSRC/WAVE Testing System



Draft SAE Message Set

- | | |
|-----------------------------|--------------------------|
| • Longitude | • Throttle Position |
| • Latitude | • Brake Applied Status |
| • Height | • Brake Applied Pressure |
| • Time | • Steering Wheel Angle |
| • Heading Angle | • Headlight Status |
| • Speed | • Turn Signal Status |
| • Lateral Acceleration | • Traction Control State |
| • Longitudinal Acceleration | • Anti-Lock Brake State |
| • Yaw Rate | • Vehicle Length |
| | • Vehicle Width |

Potential Safety Applications

Vehicles - Vehicle

- Approaching Emergency Vehicle Warning
- Blind Spot Warning
- Cooperative Adaptive Cruise Control
- Cooperative Collision Warning
- **Cooperative Forward Collision Warning**
- Cooperative Vehicle Highway Automation System
- **Emergency Electronic Brake Lights**
- Highway Merge Assistant
- Highway/Rail Collision Warning
- **Lane Change Warning**
- Post-Crash Warning
- **Pre-Crash Sensing**
- Vehicle-Based Road Condition Warning
- Vehicle-to-Vehicle Road Feature Notification
- Visibility Enhancer
- Wrong Way Driver Warning

Vehicle - Infrastructure

- Blind Merge Warning
- **Curve Speed Warning - Rollover Warning**
- Emergency Vehicle Signal Preemption
- Highway/Rail Collision Warning
- Intersection Collision Warning
- In-Vehicle Amber Alert
- In-Vehicle Signage
- Just-In-Time Repair Notification
- **Left Turn Assistant**
- Low Bridge Warning
- Low Parking Structure Warning
- Pedestrian Crossing Information at Intersection
- Road Condition Warning
- Safety Recall Notice
- SOS Services
- **Stop Sign Movement Assistance**
- Stop Sign Violation Warning
- **Traffic Signal Violation Warning**
- Work Zone Warning

Real World V-V Communication Performance



Other stuff

<https://www.mscsoftware.com/en-uk/node/654>

Adams Mechatronics

https://youtu.be/DbGTwvyT_Co

Mathworks Vehicle Dynamics

<https://uk.mathworks.com/products/vehicle-dynamics.html>



DRIVE FORCE REQUIRED

$$= \text{Rolling resistance} = mg \times \text{Coef} \mu$$

$$+ \text{Aero resistance} = 1000 \times 9.81 \times 0.015$$

$$= 147 \text{ N}$$

+ gradient resistance 0

$$= \frac{1}{2} \cdot \rho \cdot A_{\text{area}} \cdot c_d \cdot V^2$$

$$\frac{1}{2} \times 1.2 \times (2 \times 1.6) \times 0.6 \times 14^2$$

$$= 226 \text{ N}$$

TOTAL 373 N

$$\text{Power} = 373 \text{ N} \times 14 \text{ m/s} = 5222 \text{ W/s}$$

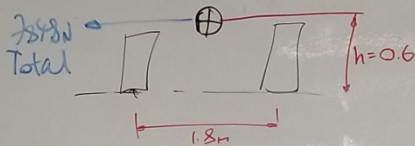
$$\approx 7.4 \text{ hp}$$

3:1 TORQUE BIASING DIFF

$$\frac{705 + (705 \times 3) - 373}{1000} = 2.447 \text{ m/s}$$

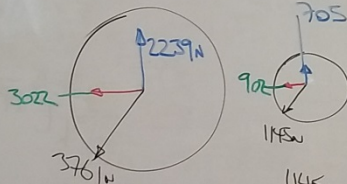
$$39.48 \text{ kW}$$

1000kg. 50/50 front rear $\Sigma = 1000 \text{ kg}$



$$\begin{array}{r} 250 \text{ kg} \\ 2453 \\ + 1308 \\ \hline 3761 \text{ N} \end{array}$$

$$\begin{array}{r} 250 \text{ kg} \\ 2453 \\ - 1308 \\ \hline 1145 \text{ N} \end{array}$$



$$\frac{3761}{4906} = 77\%$$

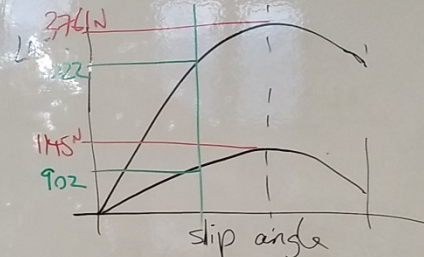
$$3924 \times 0.77$$

$$3022 \text{ N}$$

$$\frac{1145}{4906} = 23\%$$

$$3924 \times 0.23$$

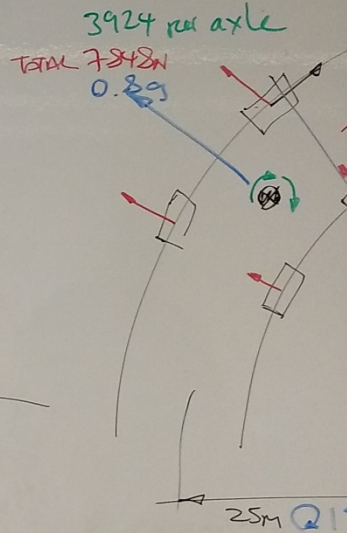
$$902 \text{ N}$$



$$3761 + 1145 = 4906 \text{ N}$$

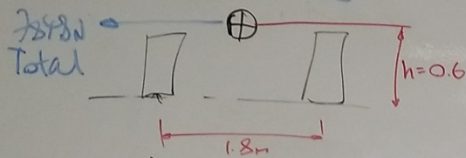
$$WT = \frac{0.6 \times 7848 \text{ N}}{1.8}$$

$$= 1308 \text{ N/axle}$$



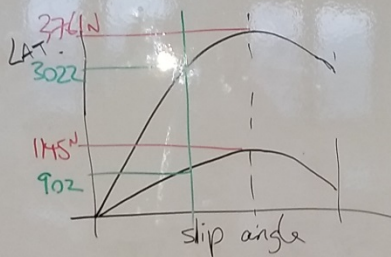
000kg. 50/50 front rear $\Sigma = 1008 \text{ kgm.}$

7.81×0.015
147 N

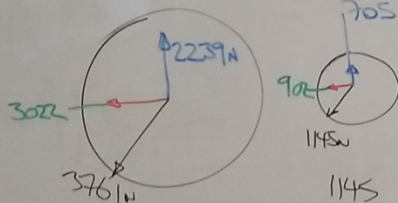


250kg	250kg.
2453	2453
+ 1308	- 1308
3761 N	1145 N

$WT = \frac{0.6 \times 7848 \text{ N}}{1.8}$
 $= 1308 \text{ N axle.}$



$3761 + 1145 = 4906 \text{ N}$

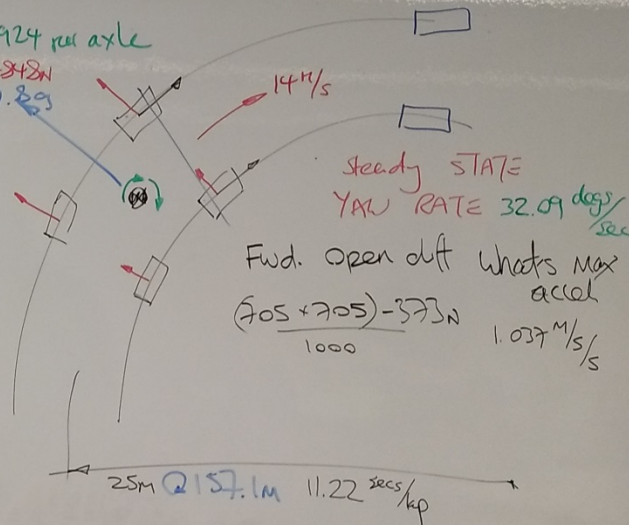


$\frac{1145}{4906} = 23\%$

$\frac{3761}{4906} = 77\%$
 3924×0.77
3022 N

3924×0.23
902 N

3924 per axle
Total 7848 N
0.2g

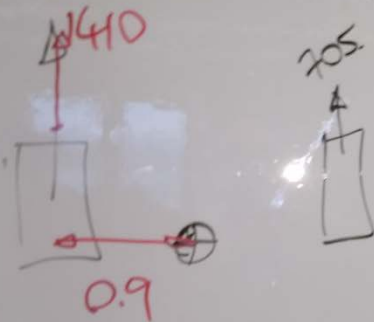


Steady STATE
YAW RATE 32.09 deg/sec
Fwd. open diff wheels max accel
 $\frac{(705 + 705) - 373 \text{ N}}{1000}$
1.037 m/s/s

25m 2157.1m 11.22 sec/kp

$$\Delta 1410 \text{ N}$$

$$2115 \text{ N}$$



$$\text{moment} = 1269 \text{ Nm}$$

$$T = I \alpha \quad \alpha = \frac{T}{I} \quad \frac{1269 \text{ Nm}}{1008 \text{ kgm}} = 1.260 \text{ rad/sec}^2$$

$$= 72.13 \text{ deg/sec}^2$$