5. EFFECTS OF ACCESSORIES, TYRES AND MACHINE MODIFICATIONS ON MOTORCYCLE DYNAMICS

5.1 ACCESSORIES

5.1.1 Fairings

A fairing is a structure added to a motorcycle to make it aerodynamically smooth and streamlined. The fairing affords a degree of protection to the rider from wind and rain and generally makes for more comfortable touring. Racing motorcycles have fairings fitted to reduce the drag coefficient and hence improve the top speed capability. Very few motorcycles are sold with fairings as original equipment, and it is generally left to the motorcyclist to choose and fit the fairing of his choice. A fairing can be mounted to the front forks, in which case it will move with the steering, or it can be attached to the main frame of the motorcycle so that the steering assembly moves independently of it.

There is evidence (Batten, 1979; Weir et al., 1978; Cooper, 1974) to suggest that fork-mounted fairings can reduce the weave or wobble mode damping to the extent that at speeds in excess of 100 km/h a dangerously large oscillation can occur. Batten (1979) stated this was the experience of the West Australian Road Traffic Authority with their Patrol Motorcycle, a Honda 750, fitted with a fork mounted fairing. Tests conducted by that Authority found that the addition of a steering damper virtually eliminated the wobble phenomenon with the fork-mounted fairing. A frame-mounted fairing tested did not cause any vibration problems, and there was no need for a steering damper with this design.

Batten also conducted a questionnaire survey of riders in 1000 single-vehicle motorcycle accidents in West Australia during the period 1976, 1977 and of part of 1978. The total number of accidents for which data were obtained was 405. There were 76 accidents which involved motorcycles with windshields, representing 18.8% of the 405 motorcycles involved in single-vehicle accidents. He also found that 13.2% of the motorcycle population in West Australia had windshields, indicating a possible over-involvement of motorcycles with windshields in single-vehicle accidents. These figures correspond to a 'relative risk' of 1.4, but as the size of the population-at-risk sample was not given, confidence limits cannot be quoted. Further, the relative contribution of steering assembly mounts versus frame-mounted fairings cannot be isolated. Interestingly, the percentage of the 405 single-vehicle accidents in which wheel wobble was reported was 13.5% with no windshield, and 18.4% with a windshield.

Weir et al. (1978) conducted a series of experimental tests to ascertain handling response and performance using a total of five different motorcycles selected to be representative of the range of machines currently available (see Section 4.2). A part of this work included a comparison of motorcycle handling performance with and without fork-mounted fairings. They employed a steady-state turn test, a single-lane-change test and straight-line running. The steady-state turn test indicated that the addition of a fairing had some effect on rider subjective ratings for the small motorcycle at low-and mid-speed. The middle-sized motorcycle's subjective handling scores were largely unaffected by the fairings, and with the very large motorcycle the ratings did not change. The single-lane-change manoeuvre showed degraded rider ratings at all speeds for the large motorcycle with a fairing. Free-control stability properties were also determined for the Honda 360 with a fork-mounted fairing. Analytical considerations established that the frequency of vortex shedding from a fairing at 100 km/h would be in the range 9 to 15 Hz, which is near the wobble mode frequency for this motorcycle. This could result in a forced vibration of the steering assembly. A series of high speed runs with the fairing were made. At a speed of about 135 km/h a sustained oscillation at approximately 3.5 Hz occurred. It was not clear whether this was a wobble or a weave; however the authors considered it to be a low frequency wobble.

Cooper (1974) investigated the effects of aerodynamics on the terminal velocity, acceleration and fuel consumption of a motorcycle. It was found that significant gains in performance occurred for road, road racing, and record-attempting motorcycles by addition of a wind tunnel designed fairing. Cooper employed the analytical model proposed by Sharp (1971) and included aerodynamic effects. His model predicted that the addition of a fairing slightly increased the weave mode damping and slightly decreased the wobble mode damping. With the extensively streamlined record motorcycles an oscillatory instability at high speeds was experienced, and the analytical model was able to predict this behaviour.

Motor Cycle Mechanics (August 1978) published results of an investigation of the effect on stability of fitting handlebar-mounted fairings. The experiments were carried out at a test track and on an ordinary road surface. The report concluded that in general all the fairings tested were safe. However, none of the fairings improved handling and none improved top speed. In all cases the fairings caused no major hazards at speeds up to 110 km/h. One of the fairings evaluated upset the high speed handling of the Yamaha RD 250 considerably. However at 110 km/h the machine was still stable. The handling of a Honda CB 400 was only slightly affected at speeds up to 130 km/h through corners.

5.1.2 Luggage Racks

Weir et al. (1978) compared the handling performance of five representative motorcycles with and without a rear-mounted load of approximately 10% of the Gross Vehicle Weight (GVW). With the steady turn and lane-change tasks oscillatory behaviour was observed in some cases. A weave oscillation resulting from the rear load being added to the Honda CB 125 is shown in Figure 5.1. This is a near-limit steady turn at 96.5 km/h on a 122 m radius turn (0.6 g lateral acceleration). The motion is slightly divergent in yaw. With the rear load, wobble motions could be induced in the Honda CB 125 using a steer torque pulse input (the handlebars are given a bump). The results were strongly speed dependent, as shown in Figure 5.2. The authors concluded that adding a rear load of 10% GVW could lead to weave oscillations, usually in near-limit manoeuvres when suspension and tyres are more heavily loaded. Addition of a large rear load decreases the wobble mode damping. With the steady-state turns, rider subjective ratings changed significantly when a 10% GVW rear load was added to the smaller motorcycles. The middle-sized motorcycles were less influenced by addition of a rear load. For the Norton 850, the rear load improved the low speed rating, and lowered its rating at high speed. With the large Harley Davidson HD 1200, the rear load decreased the medium-speed rating. Using the single-lane-change test and an added rear load, the motorcycle suspension tended to bottom in the second phase of the manoeuvre causing rider control difficulties and weaving. The load degraded rider ratings in the low and mid-speed ranges, with less noticeable effects at high speeds. Weave oscillations were observed in straight running for the smaller motorcycles carrying an added rear load. Slowing down or shifting the load eliminated these oscillations. Wobble oscillations sometimes occurred with large rear loads, probably due to the unloading effect on the front tyre and the resultant lower tyre side force coefficient.

Weir et al. (1978) deliberately attempted to bring about weave oscillations, in order that their behaviour could be studied, by adding a 45 kg rear load to the Honda 360. This represents 20% GVW (including the rider). Extreme weave oscillations at 100 km/h on a 122 m radius curve occurred, as shown in Figure 5.3. This manoeuvre corresponds to a lateral acceleration of 0.6 g and a roll angle of 31°. On reducing the

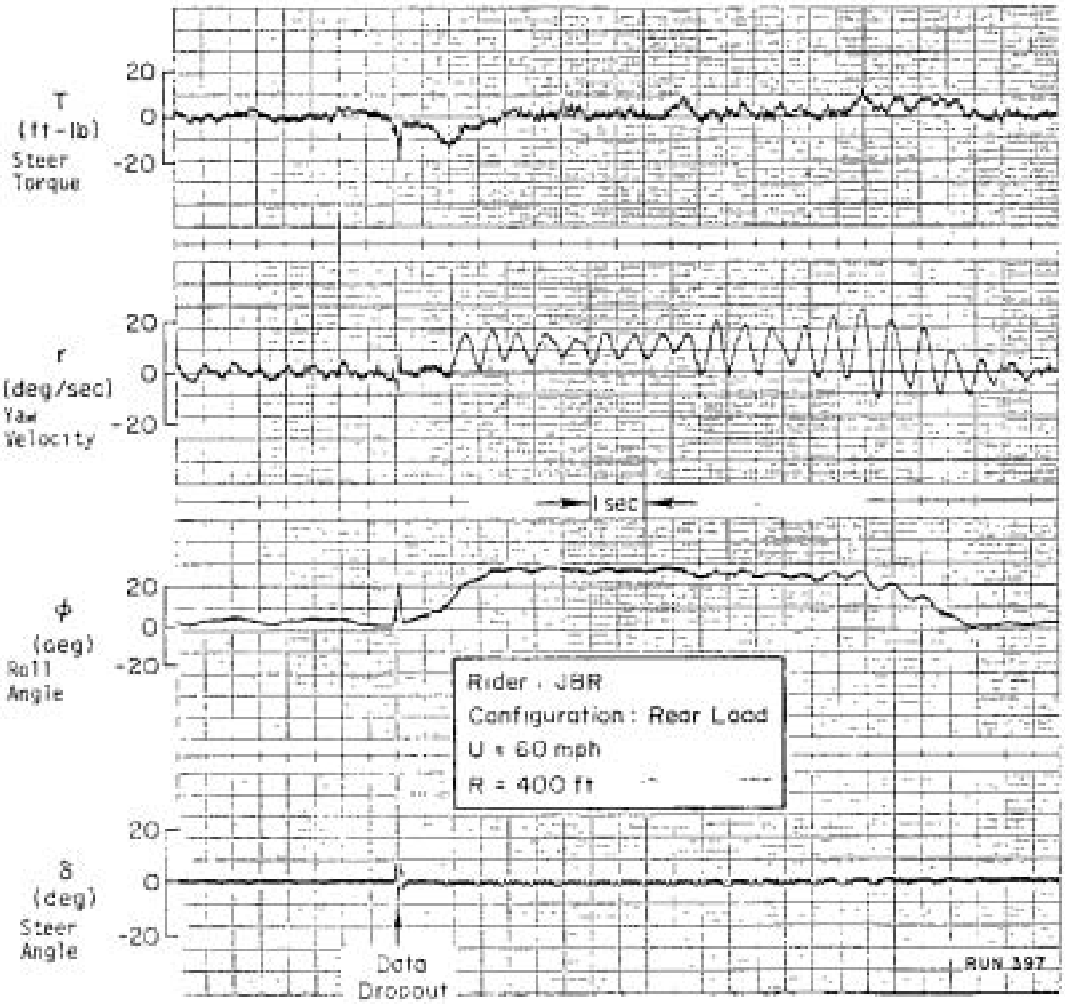

Figure 5.1 Weave divergence in a steady turn
(Weir, Zellner and Teper, 1978).

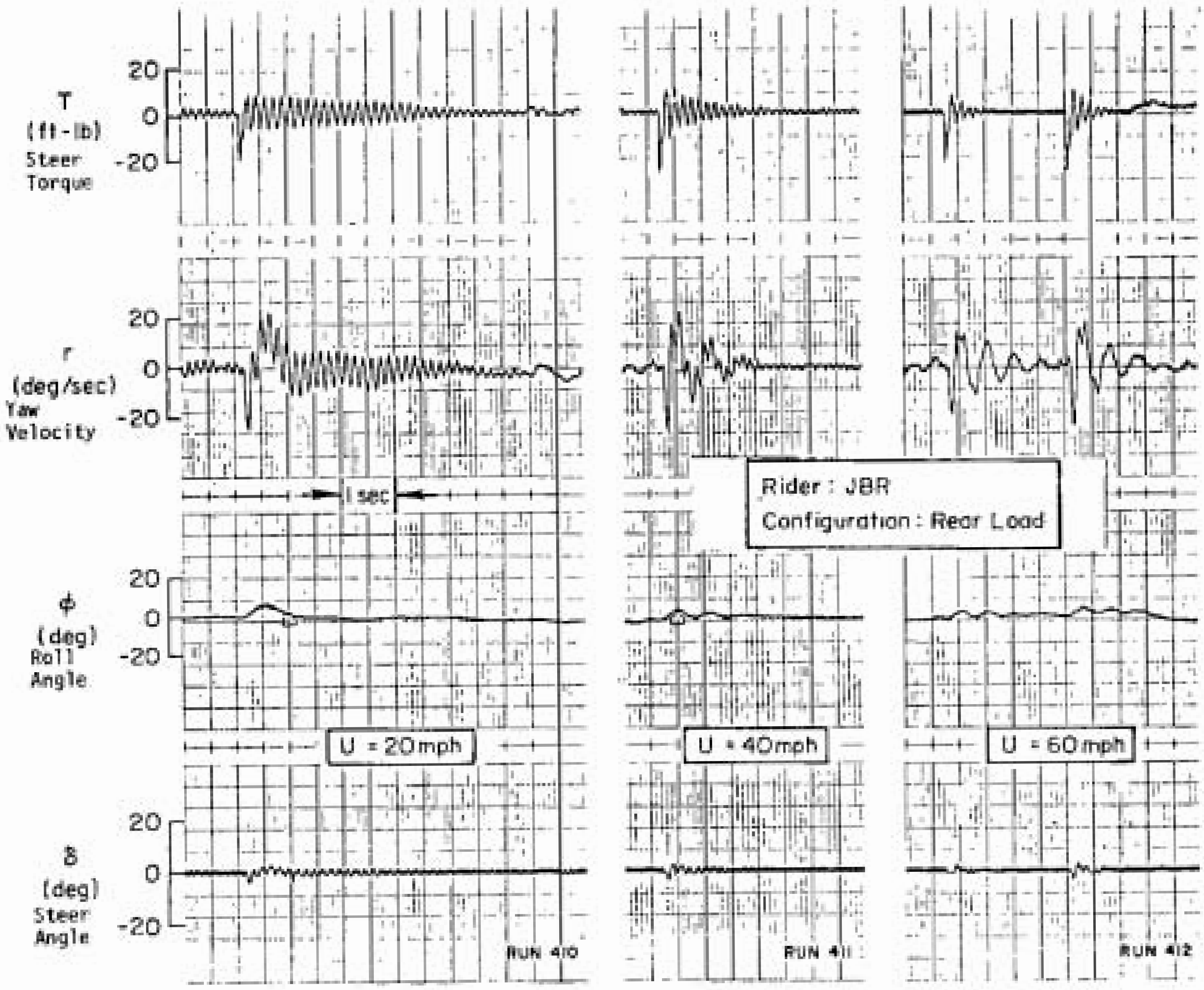

Figure 5.2 Steer torque pulse giving rise to a wobble oscillation (Weir, Zellner and Teper, 1978).

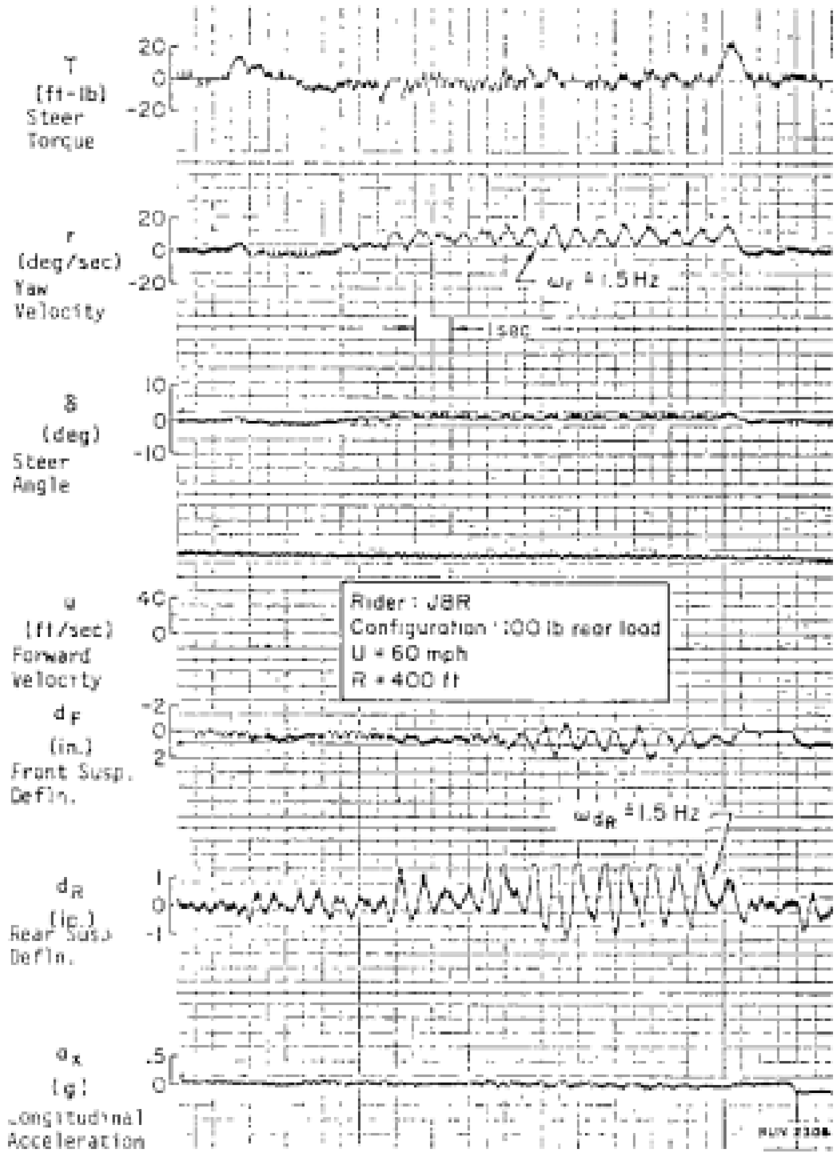

Figure 5.3 Weave oscillations in a steady turn (Weir, Zellner and Teper, 1978).

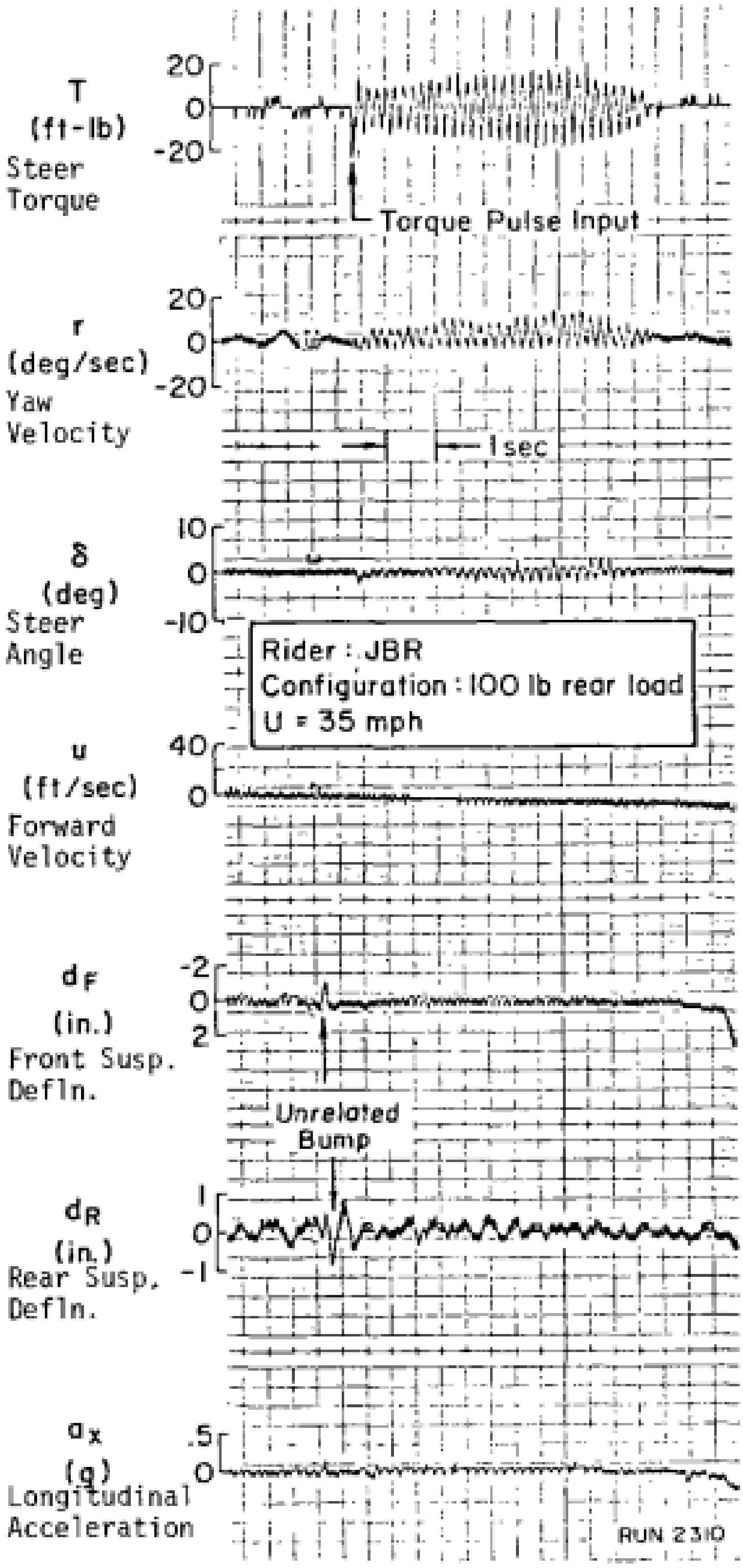

Figure 5.4 Steer torque pulse on a motorcycle carrying a rear load (Weir, Zellner and teper, 1978).

rear load to 22.5 kg, no oscillation occured at this lateral acceleration. Also, with the 45 kg load, it was possible to set up a wobble oscillation in straight-line running using a steer torque pulse: an example of this condition is shown in Figure 5.4. A wobble of about 5.5 Hz can be seen in the traces.

Further testing was done with a 22.5 kg mass added to the front assembly, 270 mm ahead of the steer axis. In straight-line tests sustained weave oscillations were observed, following a steer torque pulse, in the speed range 30 to 100 km/h. The basic motorcycle without the mass could not be forced to weave in straight-line running.

Verma (1978) investigated the compliance of a luggage rack. The natural frequency of the rack with an 18 kg load was measured in the laboratory and found to be around 10 to 13 Hz, close to the wobble frequency of the motorcycle used in Verma's work (8Hz). It could thus be expected that, with a significant load on the luggage rack, the wobble mode may be excited through sympathetic oscillations of the rack resulting from shocks or wind buffeting.

5.2 PILLION PASSENGERS

From the accident literature reviewed in Chapter 2, it was noted that there is conflicting evidence on whether motorcycles with pillion passengers are over-involved in accidents, and a suggestion that they are more prone to single-vehicle accidents.

Weir et al. (1978) included in their experimental program tests to determine effects on the dynamic behaviour brought about by carrying a pillion passenger. The results obtained were generally similar to those induced by the addition of a 10% gross-vehicle-weight rear load (discussed in Section 5.1.2). Although a passenger may contribute 15 to 50% GVW (dependent on motorcycle size), the effects cannot be simply extrapolated from the dead-weight experiments, because complex body movements may act to damp the vehicle oscillations.

5.3 TYRES

Rice et al. (1976) noted the importance of tyre characteristics for handling behaviour of motorcycles. For a motorcycle negotiating a corner, side-ways forces at the front and rear tyre contact areas are necessary for equilibrium. These forces are generated through camber angle and sideslip angle. Positive or negative slip angles are developed in conjunction with camber angle to maintain equilibrium in the turn. The effect of differing tyre characteristics is clearly shown in Figure 5.5, where a comparison of steer torque and steer angle requirements is made for two different tyres on a Harley Davidson 1200. The replacement (alternate) tyre required far less steer angle to give equilibrium conditions at a particular lateral acceleration than did the original equipment manufacturer (OEM) tyre. The replacement tyre generated more side force through camber mechanisms. The resultant steer torque requirements with the alternate tyre were far less, making the steering feel 'lighter.'

As part of his experimental program, Verma (1978) conducted runs aimed at measuring the influence of tyre condition on stability characteristics. Straight-line running tests at a range of set speeds were made and a steer torque pulse was used to excite oscillations. He intended to do three tests: one with new tyres, the next with a worn set of tyres and the third series with worn tyres and an 18 kg rear load on the luggage rack. The data acquisition system failed to operate for the second set of tests, and so controlled data with tyres being the only variable were not available. During the course of the tests with the worn tyres it was found that, for test speeds of 80 km/h and less, sustained oscillations of noticeable magnitude occurred (Figure 5.6). The addition of 18 kg rear load represents 6% gross vehicle weight. Weir et al. (1978) found that a 9% GVW rear load

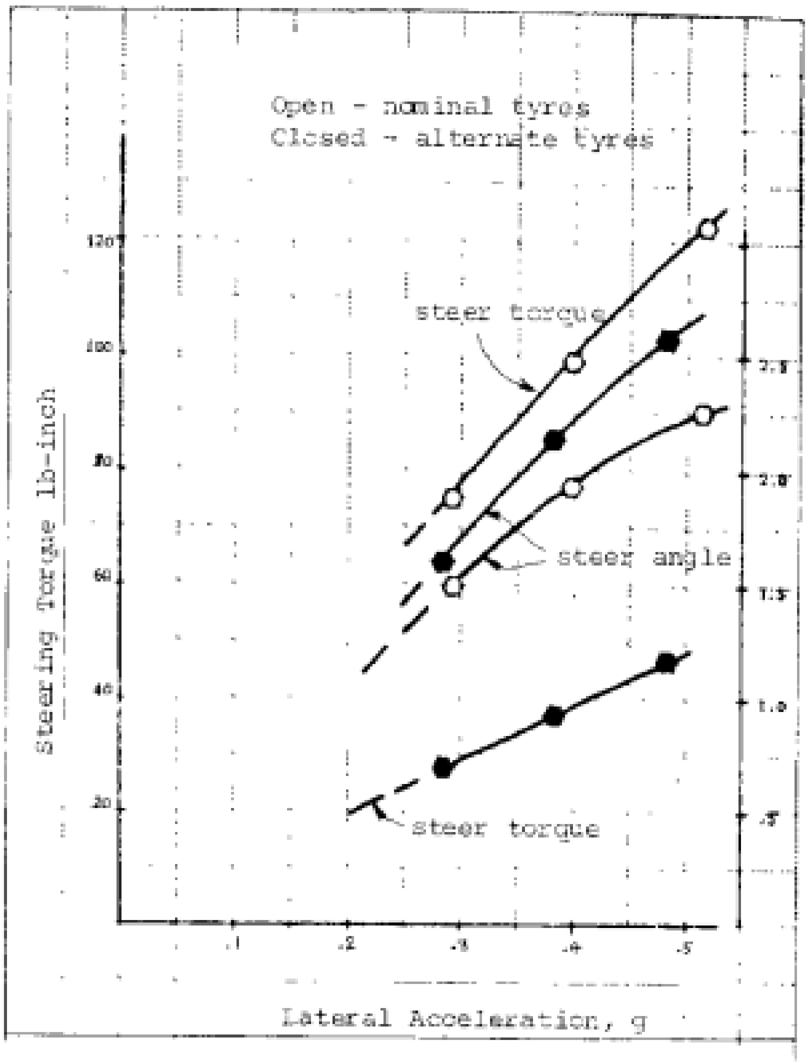

Figure 5.5 Tyre performance effects on a Harley-Davidson 1200 motorcycle (Rice, Davis and Kunkel, 1976).

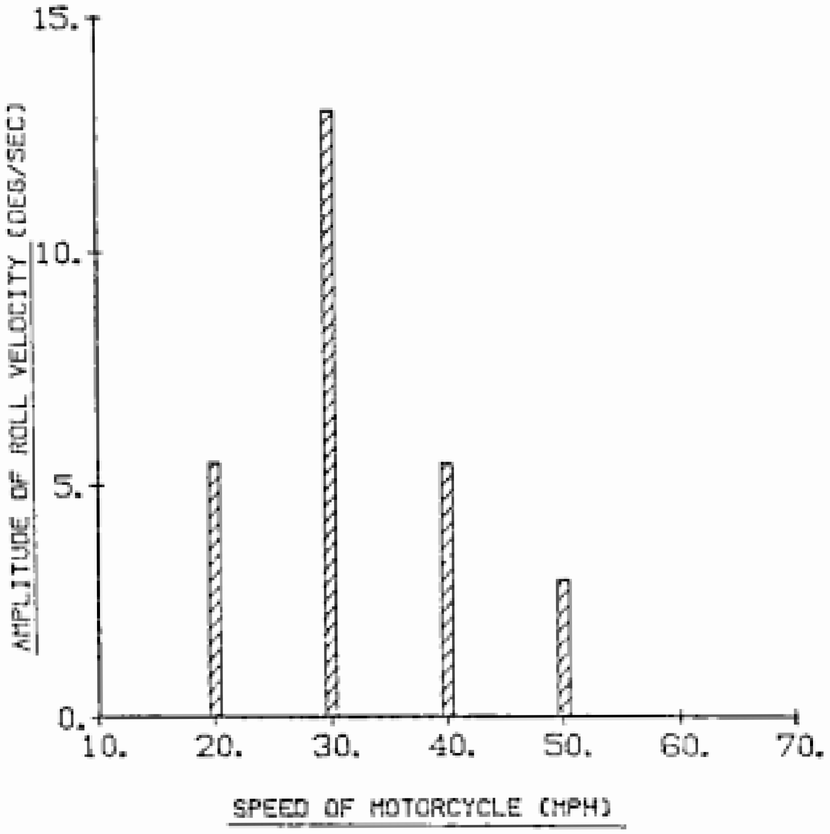

Figure 5.6 Resonance due to worn tyres, and with a rear load included (Verma, 1978).

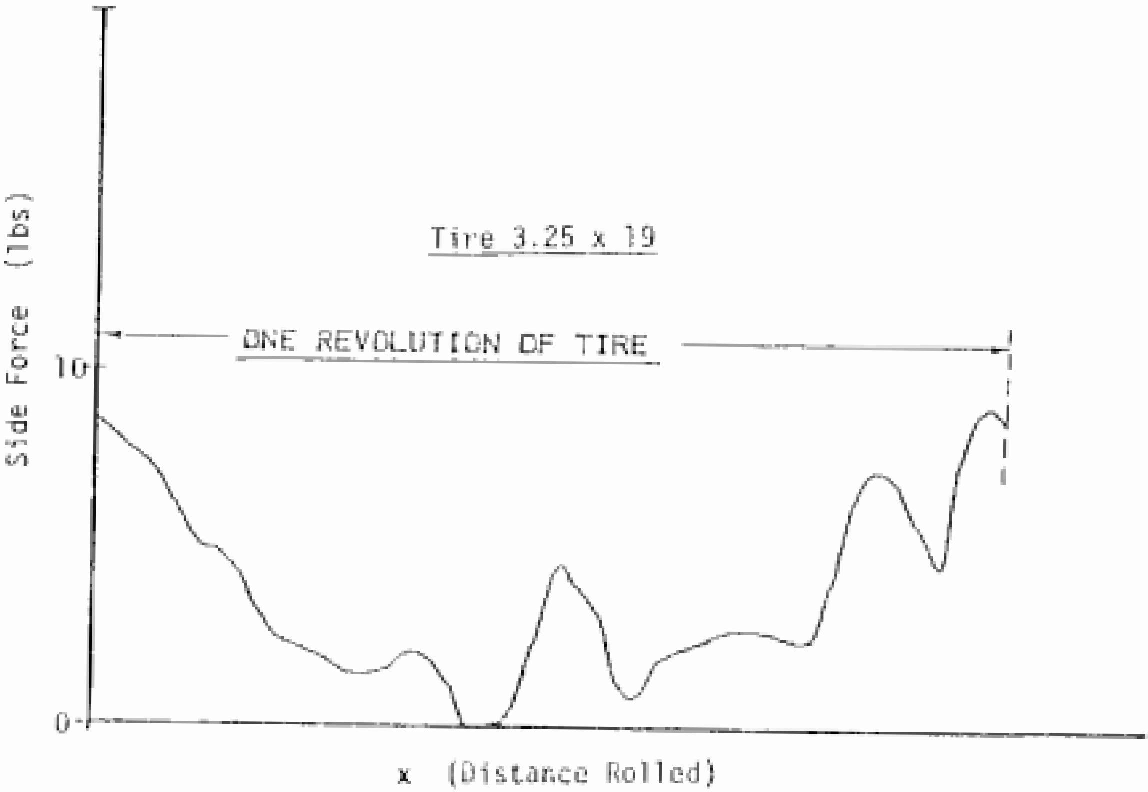

Figure 5.7 Non-uniformity of lateral force generation (Verma, 1978).

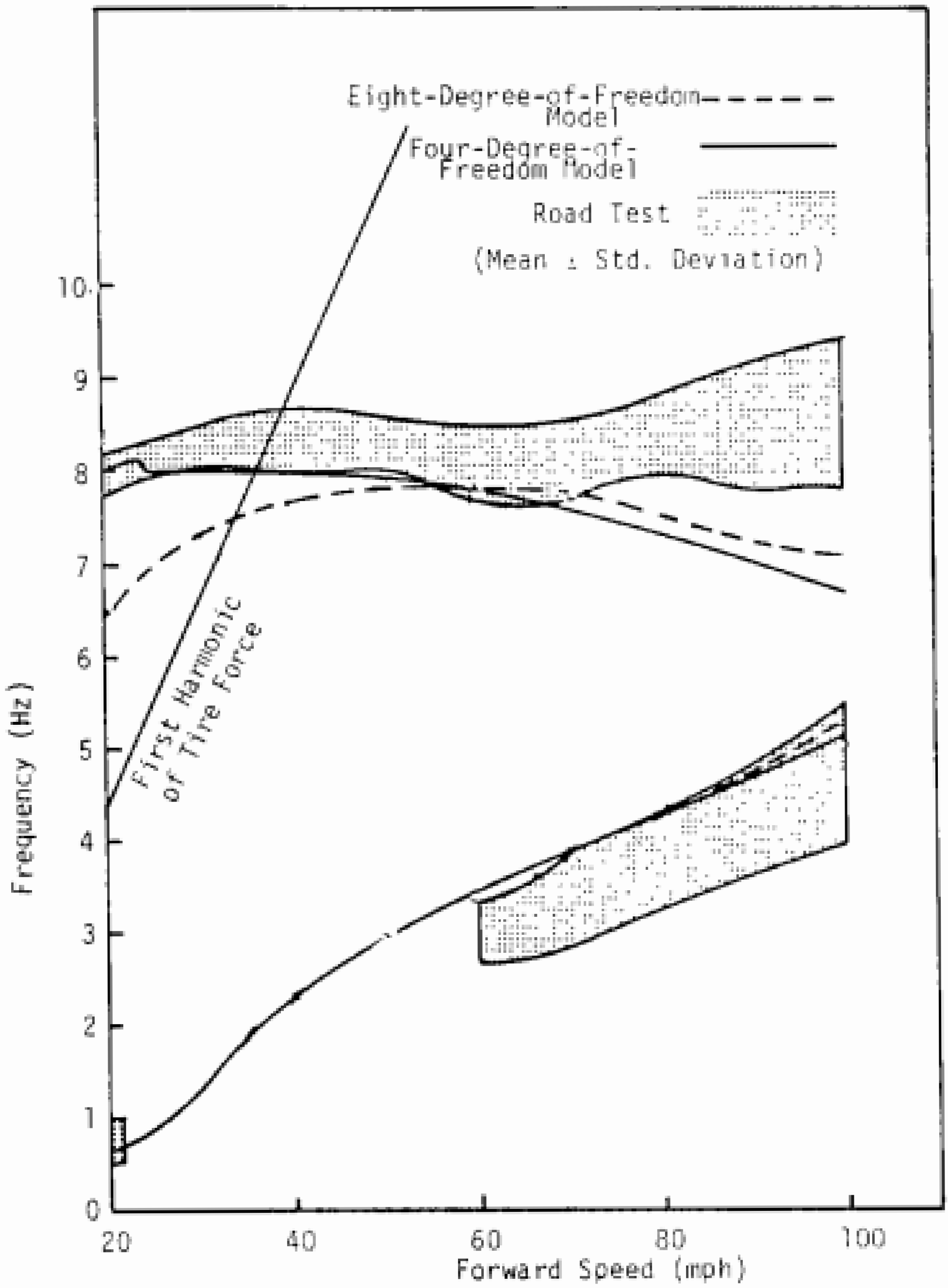

Figure 5.8 First harmonic of tyre force compared with natural frequencies of weave and wobble modes (Verma, 1978).

on a Honda 360 destabilised the wobble mode. The strong wobble oscillations encountered by Verma were possibly not entirely due to the condition of the tyres. However Verma tested the worn tyres on a flat bed tyre test machine and found the side forces generated either through side slip or camber showed periodic variations. This is shown in Figure 5.7. A harmonic analysis of the variation was performed. The frequency of side force variation resulting from tyre non-uniformity is a function of motorcycle forward speed. Figure 5.8 shows that at 64 km/h (40 mph) the first harmonic of the tyre side force corresponds to the wobble mode natural frequency. It was at this speed that the strongest oscillations were noticed.

Weir et al. (1978) pointed out that tyres have an important influence on the motorcycle's dynamic behaviour, so that all of their experimental work was made with tyres of excellent condition and correctly inflated. However there were some runs made with inflation pressure variation for the Honda 360 and the Honda 125. The results for these tests have not been reported.

Sakai, Kanaya and Iijima (1979) investigated the effect of inflation pressure and wear on the cornering stiffness and camber stiffness of both racing and standard tyres on a drum type testing machine. Figures 5.9 and 5.10 respectively show cornering stiffness and camber stiffness versus inflation pressure. The racing tyre is seen to be more sensitive to inflation pressure than the ordinary tyre. Figure 5.11 shows the effect of tyre width on camber stiffness and cornering stiffness. Cornering stiffness increases with tyre width, while only small changes in camber stiffness occur. The variations of side force and overturning moment with camber angle are affected considerably by the amount and evenness of tyre wear, as shown in Figure 5.12 and 5.13.

The results of this work clearly indicate that large variations in the tyre dynamic parameters can be effected by

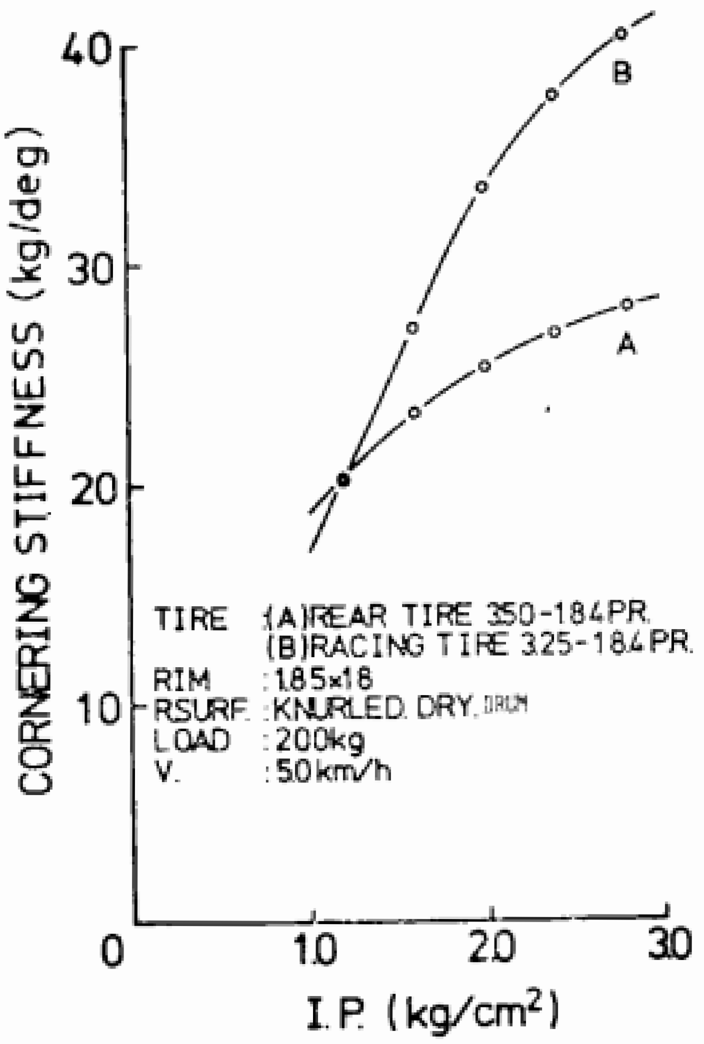

Figure 5.9 Variation of cornering stiffness due to internal pressure (Sakai, Kanaya and Iijima, 1979).

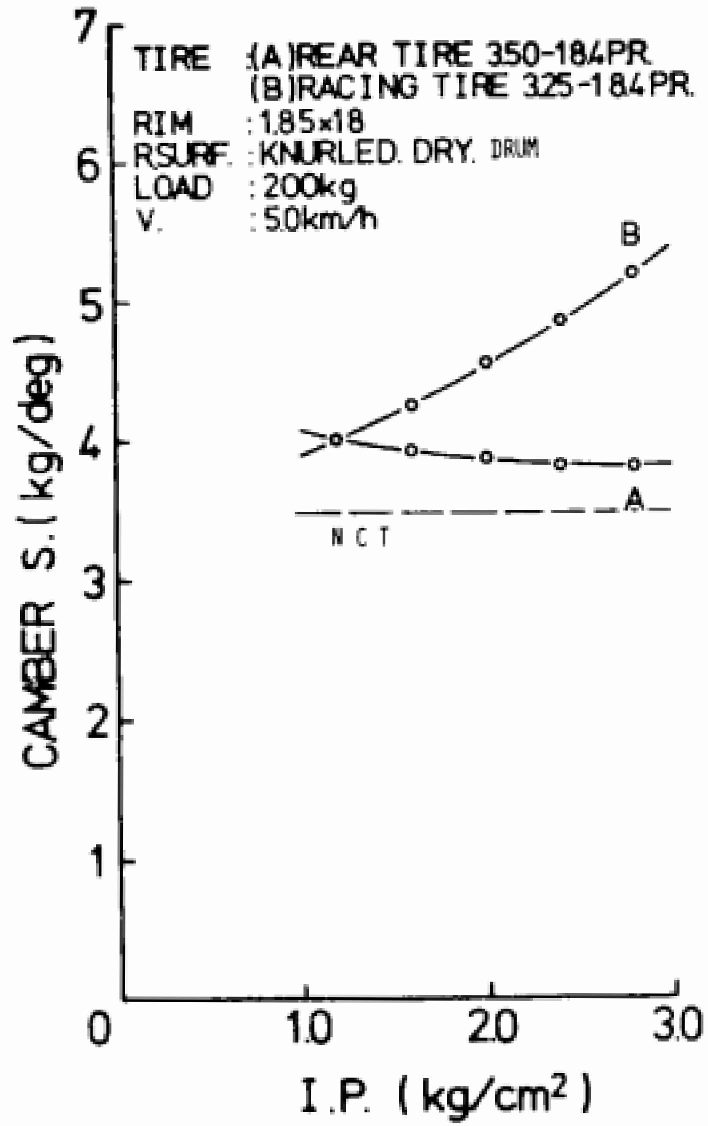

Figure 5.10 Variation of camber stiffness due to internal pressure (Sakai, Kanaya and Iijima, 1979).

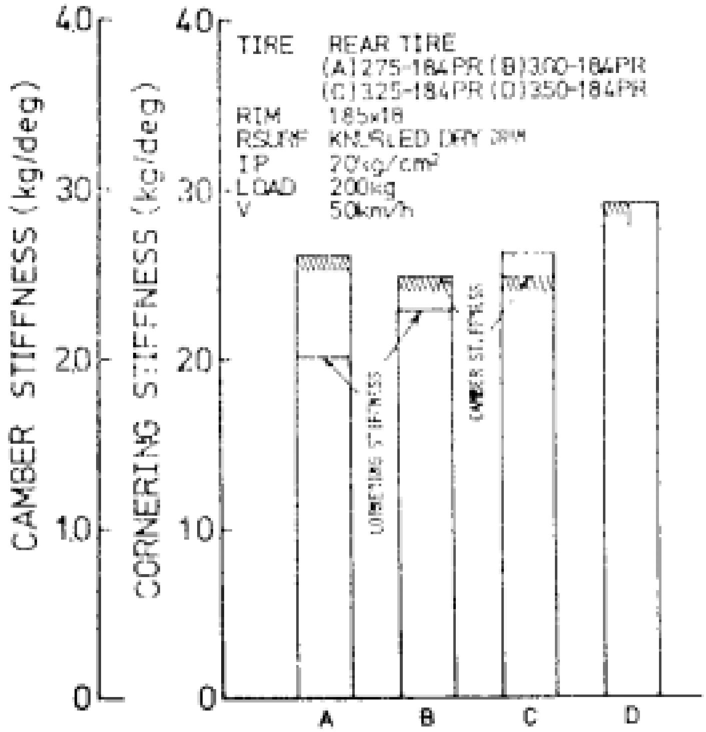

Figure 5.11 Variation of cornering stiffness and camber stiffness due to size of tyre (Sakai, Kanaya and Iijima, 1979).

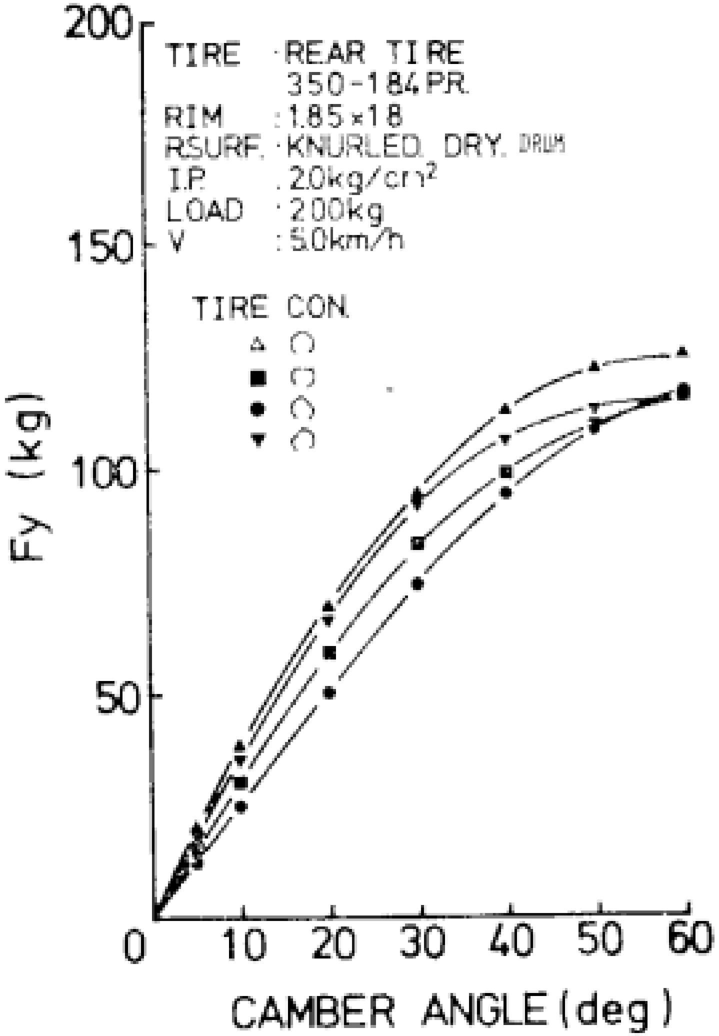

Figure 5.12 Variation of camber thrust due to wear of tread (Sakai, Kanaya and Iijima, 1979).

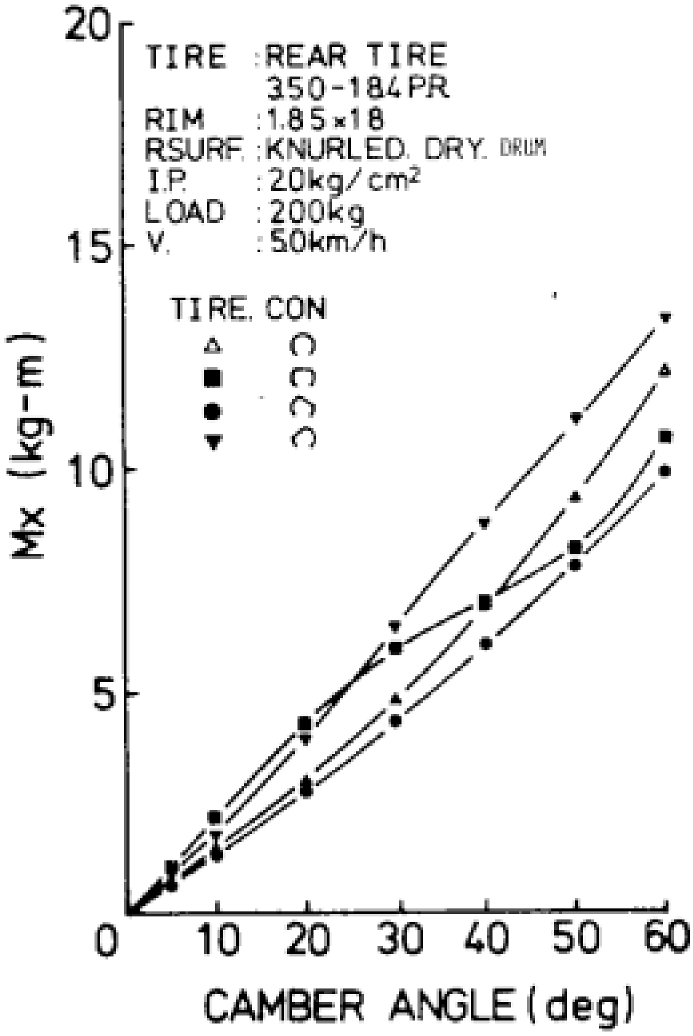

Figure 5.13 Variation of overturning moment due to wear of tread (Sakai, Kanaya and Iijima, 1979).

inflation pressure, method of construction and amount of wear, factors subject to wide in use variations. The stabilisation of a motorcycle is dependent on the generation of forces and moments through camber and steer angles. With tyre behaviour being very sensitive to these in-use factors, it can be expected that motorcycle dynamic behaviour will be similarly sensitive to such factors.

Cycle World magazine published the results of subjective and objective comparisons of fifteen rear tyres (*Cycle World*, August 1978) and thirteen front tyres (*Cycle World*, January 1979). The rear tyre subjective evaluation was conducted during ten laps of a race track type circuit, and a further ten laps on a skid pad circuit at high lateral acceleration. Both dry and wet/dry conditions were simulated during the skid pad tests (part of the track was covered with water using a hose). The motorcycle used for the skid pad tests had outriggers fitted in the interests of rider safety, as shown in Figure 5.14. The objective comparisons included measurement of tyre weight, imbalance, eccentricity, inflation pressure and tread temperature rise, lateral accelerations achieved and braking distances from 48 km/h and 96 km/h initial speeds. The front tyre testing included subjective evaluation during ten laps of a figure-of-eight circuit at near limit conditions, and the same objective comparisons as made for the rear tyre. The outrigger skid pad tests could not be performed for the front tyre, as the rear tyre always lost traction before the front tyre. Figure 5.15 shows typical summaries of the ratings and measurements for two rear tyres: one considered to be one of the better performers, and the other being representative of a tyre of lesser rating. Different brands of tyre on the same machine resulted in quite different subjective ratings of handling quality.

Figure 5.16 shows stopping distance comparisons obtained from the front tyre testing. It can be seen that there were moderately wide variations in stopping distance between brands of

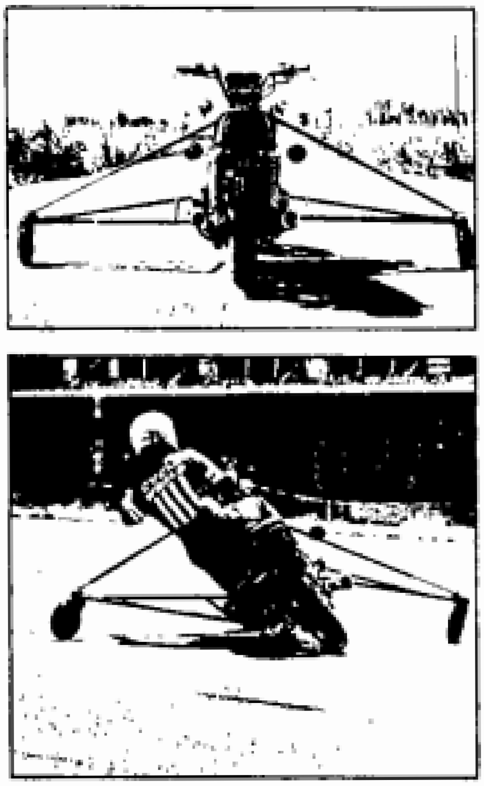

Figure 5.14 Outriggers used on motorcycles during tyre testing (*Cycle World*, August 1978).

 

Country of origin	Japan
Model	[illegible] Ontario NT183
Size	4.00H-18
Price	[illegible] F.E.T.
SPECIFICATIONS	
Diameter	25.1 in.
Width	4.55 in.
Aspect ratio	80
Footprint area	20.3 sq. in.
Tread depth	8/32 in.
Ply/ply rating	4/4
Cord material	nylon
Load range	B
Maximum load	495 lb @ 40 psi
Weight	11.0 lb
Imbalance	1.4 oz.
Eccentricity	.047 in.
[illegible]	.62
[illegible]	.60
TRACK [illegible]	
[illegible]	79°F
[illegible] tread center	110°F
[illegible] tread side	100°F
Pressure [illegible]	28 psi
Pressure [illegible]	33 psi
Braking [illegible]	77 ft.
[illegible]	81 ft.
[illegible]	fair/poor
Braking [illegible]	274 ft.
[illegible]	fair/poor
[illegible]	poor
[illegible]	poor
[illegible]	poor
SKIDPAD [illegible]	
Temperature [illegible]	92°F
[illegible]	115°F
[illegible] tread side	142°F
Pressure [illegible]	28 psi
Pressure [illegible]	28.5 psi
Lap time [illegible]	14.02 sec.
Lap speed [illegible]	30.6 mph
[illegible]	0.628 g
[illegible]	poor
Lap time [illegible]	9.59 sec.
Lap speed [illegible]	21.7 mph
Degree [illegible]	fair

Figure [illegible] tire [illegible] test results

[illegible]

tyres: a 16% variation overall for the 50 km/h stops and 26% for the 100 km/h stops.

Kokoschinski (1978 a, and b) performed tests on 22 different motorcycle tyres in order to rate them on a comparative basis. The program, which was reported in the German magazine *Motorrad*, included subjective assessment by expert riders at Nurburgring race track. Six motorcycles of three different sizes were used: two Hercules K 125 S, two Yamaha RD 400 and two BMW R 100 S. The small machines' behaviour was not influenced by different tyres, for two main reasons: firstly, the suspension bottomed well before limit tyre conditions were approached during cornering; secondly, not enough power was available for straight-line limits to be reached. The medium and large motorcycles were, however, influenced by tyre type. The tyres rated best were said to 'have the common property that they noticeably stabilise the machine in fast straight-line driving and that they generate lateral forces in curves such that the limit of adhesion was never reached.' Some of the tyres rated otherwise as good were said to 'steer into a curve with some reluctance', or to have 'a certain inertia when steering into alternate curves.' The worst-rated tyres were found to have 'little tracking stability' during initial braking and skidded at the rear during acceleration. Furthermore, 'they did not instil much confidence in their adhesion values during curve driving.'

Objective measurements of the tyres were made at a tyre factory. These measurements showed quite wide differences in quality control of tyre uniformity (radial and lateral deviations), the speed of response of tyre side force to change in slip angle, and the steady-state side forces developed in response to sideslip and camber angles. Generally, the ranking of tyres according to these objective measurements was consistent with the subjective ratings obtained on the medium and larger size bikes.

Stopping Distances, Front Brake Only, In Feet (Listed in order of combined 30 and 60 mph stopping distances)		
	30 mph	60 mph
Goodyear	32	140
Carlisle	36	145
Michelin	36	146
Cheng Shin	38	145
Continental	36	150
Nankang	35	154
Dunlop	38	152
Pirelli	37	155
IRC	34	164
Yokohama	37	164
Avon	36	167
Bridgestone	37	171
Nitto	38	176

Figure 5.16 Stopping distance using front brake only with different tyres (*Cycle World*, January 1979).

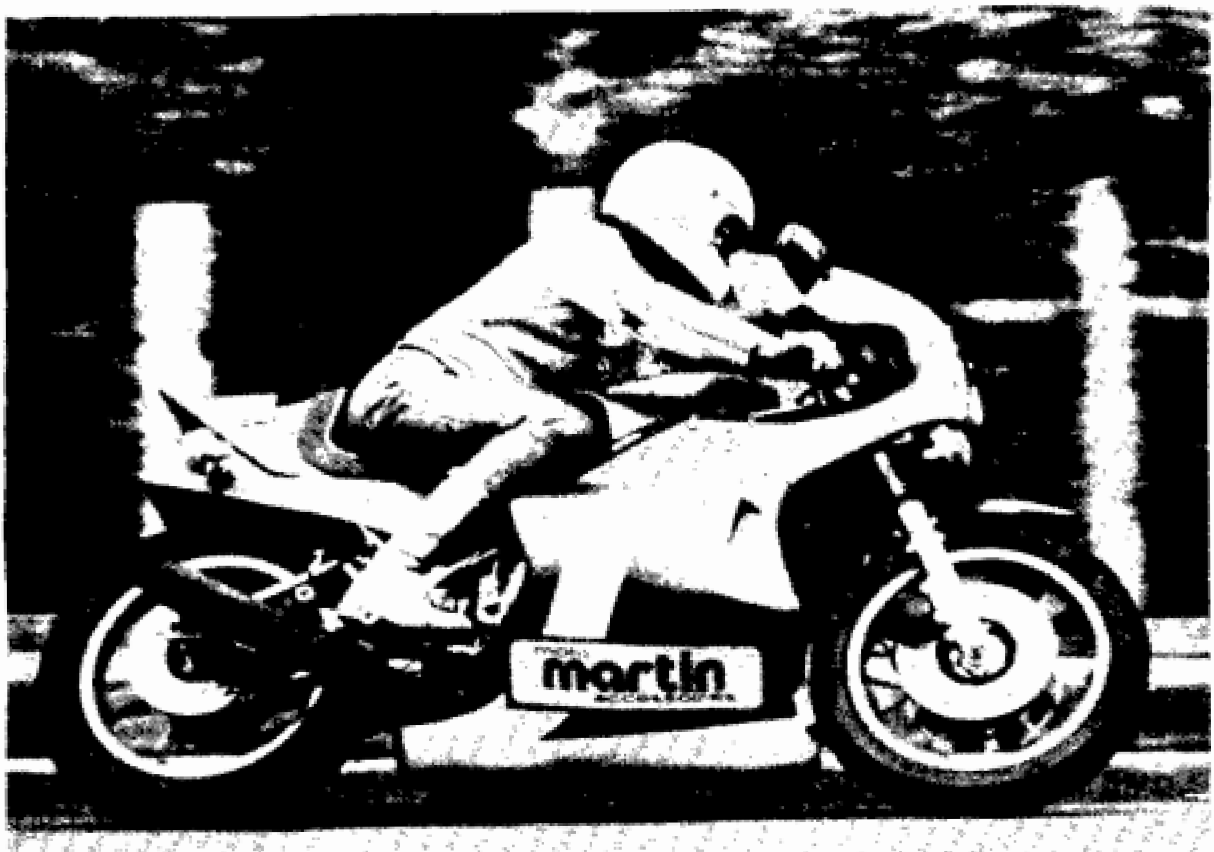

Figure 5.17 A 'Cafe Racer' motorcycle (*Australian Motorcycle News*, Vol. 29, No. 2, 1979).

The *Cycle World* and *Motorrad* tests showed that different brands of tyre lead to a wide range of ratings of 'confidence in tyre', 'degree of control' and so on. This confirms the conclusions from mathematical simulations of handling behaviour that tyre characteristics play an important and subtle role in the machine's behaviour. It would be desirable to be able to predict handling quality from a knowledge of the motorcycle and tyre characteristics. The present state of knowledge is inadequate for this, however. Further research is required into the mechanics of tyre force generation and, indeed, into what constitutes 'good' handling behaviour.

5.4 MACHINE MODIFICATIONS

Motorcycle riders often show their desire to express individuality by modifying their standard motorcycle to make it look different from the rest. These modifications may include improved engine performance, low handlebars, rear-set foot pegs and a fairing. A motorcycle thus modified is sometimes called a 'Cafe Racer' - see Figure 5.17. At the other end of the scale, the owner may extend the front forks, shift the foot pegs forward, lower the seat and instal a pack rack called a 'sissy bar'. These machines are called 'Choppers' (Figure 5.18). Motorcycle dynamic characteristics are particularly sensitive to the geometry of the steering assembly, and so licensing authorities in Australia do not permit extension of front forks beyond 250mm. (The state of Queensland does not permit any modifications).

Weir (1972) attempted to determine the effect on handling performance of changing motorcycle design configuration. He analytically compared a conventional motorcycle with a chopper variation. The latter involved increasing frame and fork rake angle, extending forks, lowering the rider seating position, and changing the inertial properties of the wheels. The comparison lacked experimental verification. However, he was able to

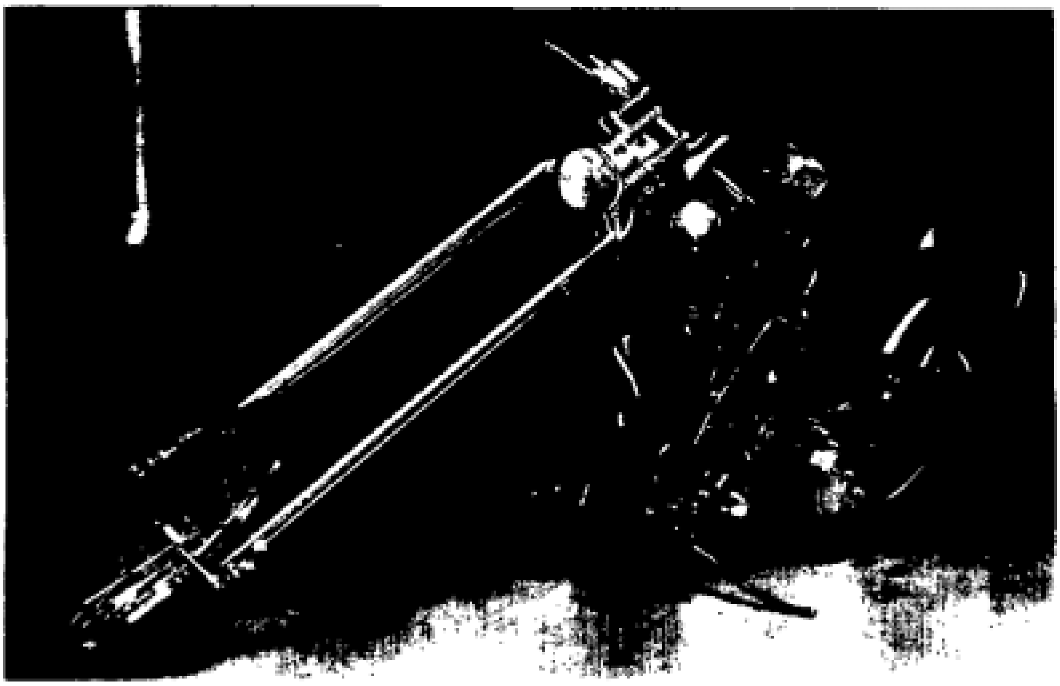

Figure 5.18 A 'Chopperised' motorcycle (*Supercycle*, November 1979).

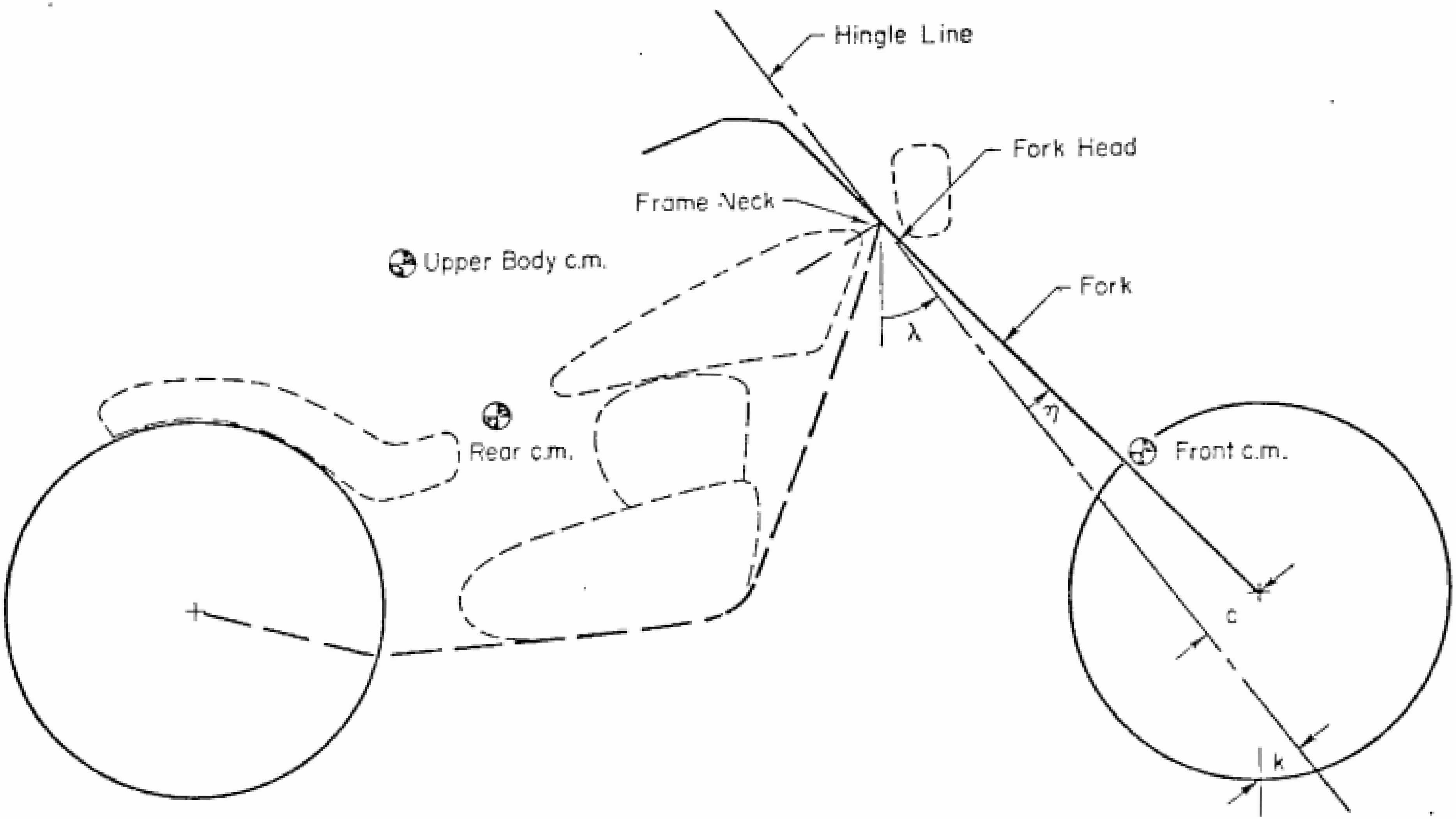

Figure 5.19 Nominal chopper configuration (Weir, 1972).

conclude that fine tuning of a chopper chassis could result in a motorcycle with overall handling properties about the same as the basic conventional motorcycle, and with improved high-speed cruising characteristics. The most important consideration with frame tuning was the provision of positive trail under all loading conditions, both static and dynamic. Figure 5.19 shows the machine analyzed, with the dimension 'k' being the trail mentioned above. Weir comments that the process of chassis tuning to achieve good handling is particularly complex because of the extensive coupling in the equations of motion and 'in view of this complexity and sensitivity, it is in some ways remarkable that standard and chopper motorcycles have evolved, and that they are commonly used by riders of all skill levels.'

5.5 CONCLUSIONS

Fairings

(i) A linear mathematical model of motorcycle lateral dynamics which includes the aerodynamic characteristics of a fork-mounted fairing indicates that the wobble mode damping is decreased at high speeds by the presence of a fairing. The frequency of vortex shedding from a fairing may also coincide with the wobble mode natural frequency, thus exciting a resonant wobble oscillation.

(ii) Field experience with police patrol motorcycles has shown that fork-mounted fairings can indeed cause steering wobbles at speeds in excess of 100 km/h.

(iii) One experiment found that subjective ratings of handling quality were degraded by the presence of a fork-mounted fairing, especially for smaller motorcycles.

(iv) Tests conducted by a motorcycling magazine, however, did not reveal any major problems with fork-mounted fairings, except for a light motorcycle, and then only at very high speeds.

Loads

(v) Addition of a rear load of 10% Gross Vehicle Weight (GVW) can lead to weave oscillations in near-limit manoeuvres.

(vi) A pillion passenger has been found to influence the motorcycle dynamic behaviour similarly to the addition of 10% GVW.

(vii) A flexibly-mounted rear luggage rack carrying a substantial load may cause wobble oscillations due to a coupling of the rack vibrations with the steering motions.

(viii) Weave mode instability may be induced by the addition of mass forward of the steering axis.

(ix) The deleterious effects of added loads generally require fairly extreme loadings or manoeuvres to become a significant problem.

Tyres

(x) Tyre characteristics can influence the steering 'feel' properties to a large degree. Large variations in tyre dynamic parameters can result from differences in inflation pressure, method of construction and amount of wear. These are all 'in-use' tyre factors subject to wide variations.

(xi) 'Expert' riders are able to rate different tyres on a subjective basis, with consideration given to their ability to stabilise the machine in fast straight-line driving, the level of cornering adhesion limits, and their high-deceleration braking characteristics. However, it is not yet possible to predict motorcycle handling qualities from objective measures of machine and tyre characteristics.

Modifications

(xii) A 'chopperised' motorcycle can be made to handle much the same as a standard motorcycle. To do this, however, it is necessary to pay careful attention to the rake and trail measurements.

6. FINDINGS AND RECOMMENDATIONS FOR FURTHER RESEARCH

6.1 ACCIDENT LITERATURE REVIEW

Motorcycling is popular for both commuting and leisure activities. It is hazardous, however, in comparison with automobile driving, both in terms of relative frequency and severity of accidents. In the event of an accident the rider is at very great risk, and usually makes contact with another vehicle or the ground. The injuries suffered are usually severe.

The typical motorcycle accident involves a collision with another vehicle, usually an automobile, and in the urban/suburban environment. The motorcycle is generally travelling straight, and a vehicle turns across its path. Culpability largely rests with the driver of the other vehicle.

In an accident situation when braking is attempted, the rider typically does not utilize the full braking capability of the motorcycle. A large accident study found that motorcyclists had applied both front and rear brakes together in only half of the cases in which braking was attempted. The reduced deceleration being achieved by riders results in increased impact speeds, and thus accidents of greater severity than need be the case.

Motorcycle braking performance usually deteriorates in wet weather and accident data confirm that riders are then at greater risk. Perhaps partly as a result of this, wet weather riding is greatly reduced and the magnitude of the accident problem is similarly reduced.

Motorcycles have motion instabilities that, when excited, are beyond the capabilities of the rider to control. However, they are mostly high speed phenomena and, as most accidents occur within the 60 km/h speed limit zones, these problems do not appear to be of great concern.

The effect of motorcycle handling characteristics on accident risk has not been studied, due in part to a lack of knowledge of appropriate ways to characterize handling qualities. The most common loss of control accident involves the machine running wide on a turn. The presence of a pillion passenger, or lack of familiarity with the motorcycle increases the likelihood of a single-vehicle accident. Modified machines are apparently not over-represented in accidents.

6.2 MOTORCYCLE BRAKING

The performance of disc brakes in wet weather deteriorates rapidly, as they suffer increased response time and require higher input force levels to achieve dry-brake deceleration levels. The Transport Road Research Laboratory, in conjunction with Dunlop, have developed a sintered metal pad which appears to overcome these problems. At this time only one motorcycle manufacturer (Kawasaki) is known to be supplying these pads as original equipment.

Aspects of the testing requirements for motorcycle and moped braking systems, contained in Australian Design Rule No. 33, are considered to be inadequate, as the brake environment in wet conditions is not well simulated.

Linked brake systems provide front and rear brake application simultaneously, thus eliminating the problem of the rider using only one brake in an accident avoidance manoeuvre. Only one manufacturer (Moto Guzzi) supplies motorcycles with a linked braking system. Investigations are recommended to assess their performance under varying conditions and with riders of different levels of skill. Furthermore, a system which allows for varying levels of deceleration and the presence or otherwise of a pillion passenger should be researched.

Experimental work has shown that antilock brakes provide superior performance to standard brakes, particularly when the road surface is slippery. Several systems are at the prototype development stage.

The ergonomics of the separate front and rear brake systems found on nearly all motorcycles have not yet been subjected to scientific scrutiny. As the characteristics of these systems vary greatly from motorcycle to motorcycle, it is expected that such a study should lead to systems with more universal appeal, providing better deceleration performance.

6.3 STABILITY AND HANDLING CHARACTERISTICS

Analytical simulations of the motorcycle-alone and the rider/motorcycle system in various maneouvres have identified the major dynamic modes of the motorcycle (weave, wobble and capsize), rider control strategies in making a turn, and pitch/weave coupling effects in high lateral acceleration cornering. These models now offer a fairly accurate representation of the motorcycle dynamics. Further work is required with tyre models and rider representation. A validated rider/cycle model would be a valuable tool to safely and economically investigate the effects of a variety of motorcycle design parameters and machine modifications.

An investigation into obstacle avoidance showed that lightweight motorcycles did not perform any better than medium or heavy machines. A rider with low skill required about 15 to 20% more distance to avoid the obstacle than skilled riders. These tests also showed that a motorcycle should not be considered more manoeuvrable than an automobile in obstacle avoidance.

The oversteer/understeer characteristic used to describe automobile handling has been investigated as a motorcycle handling parameter. Riders preferred a motorcycle with neutral to modest oversteer properties. They also preferred a machine with a well-damped, stable weave mode at high speed. The results of lane change experiments showed that riders prefer a motorcycle which begins to yaw initially rather than the first response being a change of roll angle. However, only very tentative conclusions have been drawn about desirable handling response properties, and the study of motorcycle handling is in its infancy.

Anecdotal evidence gleaned from the popular press suggests existence of problems such as high speed weaving, high speed wobbles, slow response at low speed, self steering, and roll limits imposed by footpegs, mufflers and stand brackets. Tyres have a large influence on ratings of steering and handling behaviour, and disc brake performance in wet weather is not regarded as satisfactory. Further work is required to quantify these effects.

6.4 EFFECTS OF ACCESSORIES, TYRES AND MACHINE MODIFICATIONS ON MOTORCYCLE DYNAMICS

A fairing mounted on the forks can give rise to wobble oscillations at speeds in excess of 100 km/h. This can be eliminated by addition of a steering damper, or by mounting the fairing direct to the motorcycle main frame. The degradation of rider rating due to fitting a fairing is greatest with small motorcycles.

Addition of 10% GVW to the rear of a motorcycle can lead to weave instability during near-limit cornering. A weight added ahead of the steering axis may give rise to weave oscillations. A pillion passenger has a similar effect on motorcycle handling as addition of 10% GVW.

Motorcycle behaviour is strongly influenced by tyre pressure, condition and design. A large variation in machine characteristics is obtainable by altering the type of tyres fitted to it.

A 'chopper' motorcycle with extended front forks, could be made to handle much the same as a standard motorcycle, if proper attention was given to tuning the rake and trail dimensions of the steering assembly.

6.5 RECOMMENDATIONS FOR RESEARCH

In the field of braking, stability and handling of motorcycles, a number of areas requiring research have been identified. The accident data suggest that highest priority should be given to braking studies. It is clear that riders are not utilizing the full braking capacities of their machines. Although stability and handling research would appear to have lower priority, it should be noted that very little is in fact known (in a scientific sense) about motorcycle handling. Thus, it is unlikely that accident investigators will have been able to make adequate judgements about the role of handling characteristics in accidents.

Specific research topics, arranged roughly in order of priority, are as follows:

1. <u>Braking</u>

The separate front and rear brake controls found on nearly all motorcycles have characteristics which vary greatly from machine to machine. An experimental study to quantify these characteristics and to analyse the ergonomic capabilities of riders in controlling brakes should be undertaken. This should result in provision of motorcycle brake systems in which riders have confidence and which will improve their utilization of the braking potential of their machines.

1.2 Linked braking systems have many advantages, mainly in that they prevent the use of only the rear brake in an accident situation and hence maximise deceleration. Development of a variable proportioning system to optimally distribute braking effort, based on deceleration level and the presence or otherwise of a pillion passenger, should be initiated. The performance of such a system with a range of brake and tyre/road friction conditions, and with riders of varying skill, should be investigated.

1.3 Australian Design Rule No. 33 - Motorcycle and Moped Braking System has been shown to assess wet weather brake performance inadequately. The procedure should be modified to incorporate a more realistic wetting technique which would model the actual wet weather brake environment more closely. This technique should be the subject of a research project.

1.4 Antilock brakes are seen to be an ideal solution for obtaining maximum deceleration with unskilled operators and when conditions are wet and slippery. However, at this time they are prohibitively expensive, and are not available as standard equipment. Overseas developments in this area should be monitored.

2. Stability and Handling

2.1 As yet, parameters which adequately characterise motorcycle handling quality have not been established. A combined experimental and analytical research program is required to identify optimum handling response characteristics for a motorcycle. It can be anticipated that a motorcycle which is matched to the control capabilities of the rider will reduce the work load in stabilizing and controlling the machine, thereby increasing his capacity to deal with traffic events. This should have a favourable influence on accident statistics.

On completion of this fundamental work on motorcycle handling, research into a number of important aspects of in-use behaviour could be approached on a rational basis. For example, there is a need to:

(i) Quantify the influence of tyre pressure, wear and design on motorcycle stability and handling. This would lead to recommendations being established for users.

(ii) Enable safe limits for carrying of load and passengers to be established.

(iii) Measure the changes in characteristics arising from fitting various designs of fairings, with different methods of attachment, and hence make recommendations.

(iv) Conduct an accident study designed to measure the role of stability and handling characteristics in accidents.

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APPENDIX A

A.1 DERIVATION OF SIMPLE MOTORCYCLE BRAKING EQUATIONS

The following derivations intend to show the effect of using front and rear, front only and rear only brakes for decelerating a motorcycle in a straight line on level surface.

A.1.1 Front and Rear Brakes Applied Together

Referring to Figure A.1, and assuming that the brakes are applied to the limit of available friction between tyre and road surface, equilibrium conditions yield:

$$\Sigma M_{x_1} = 0$$

$$N_f(a + b) = mgb + mDh$$

where D is the deceleration

$$\therefore N_f = m/\ell(gb + Dh) \qquad (A.1)$$

$$\Sigma M_{x_2} = 0$$

$$N_r(a + b) = mga - mDh$$

$$\therefore N_r = m/\ell(ga - Dh) \qquad (A.2)$$

$$\Sigma F_x = 0$$

$$\therefore H_r + H_f = mD \qquad (A.3)$$

Let μ = friction coefficient between tyre and road, then it follows that:

$$H_f = \mu N_f \qquad (A.4)$$

$$H_r = \mu N_r \qquad (A.5)$$

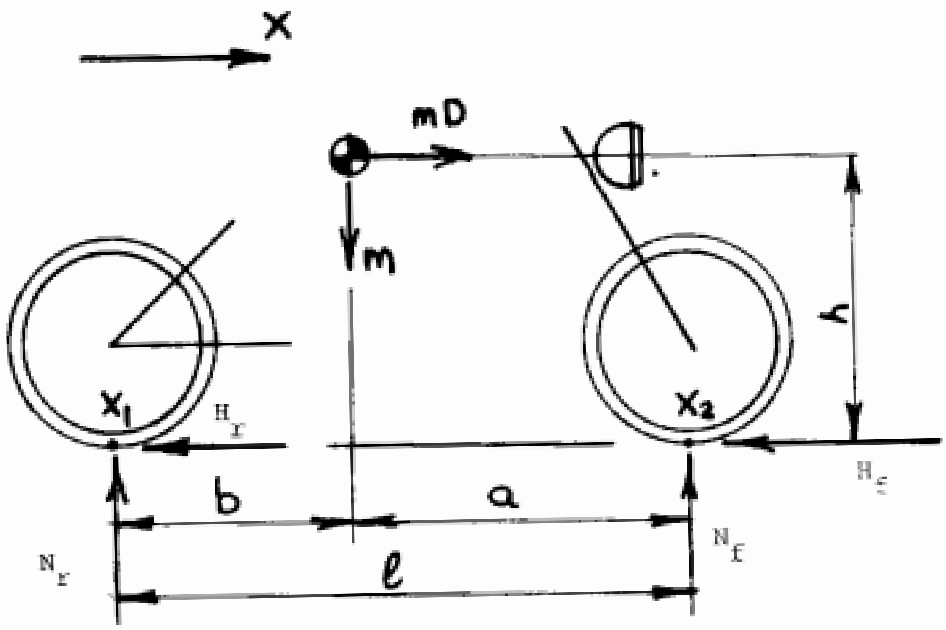

Figure A.1 Basic dimensions of motorcycle, front and rear brakes applied.

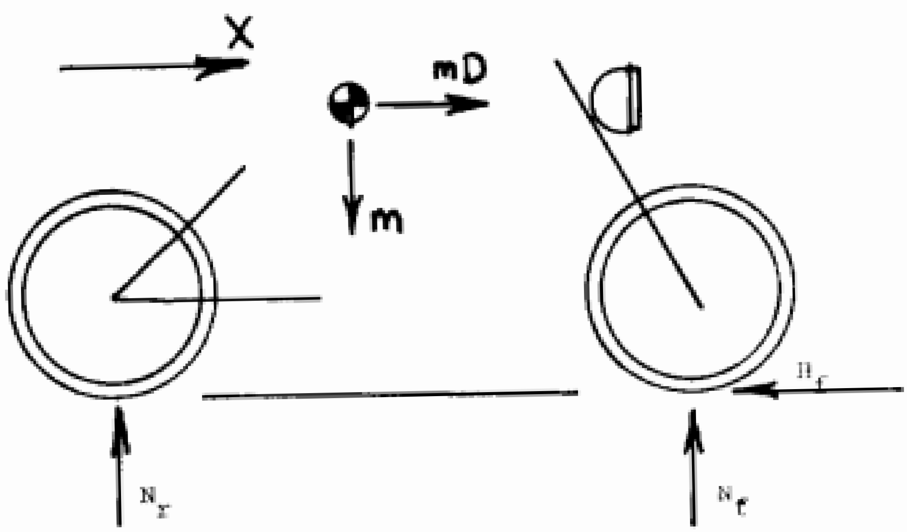

Figure A.2 Motorcycle with front brakes applied.

Substituting A.1, A.2, A.4 and A.3 yields:

$$D = \mu g \quad (A.6)$$

A.2.1 Front Brakes Applied Alone

Referring to Figure A.2, it can be shown that:

$$H_f = mD \quad (A.7)$$

So; substituting A.4 and A.1 into A.7 yields:

$$D = \mu gb/(\ell - \mu h) \quad (A.8)$$

A.1.3 Rear Brake Applied Alone

Referring to Figure A.3, it similarly follows that:

$$H_r = mD \quad (A.9)$$

So that:

$$D = \mu ga/(\ell + \mu h) \quad (A.10)$$

Using the data for six motorcycles covering the range from lightweight commuter to heavyweight tourer (Rice et al., 1976), a graph of percentage of available deceleration obtained using front and rear, front only and rear only brakes versus tyre/road friction coefficient was plotted and is shown in Figure 3.10.

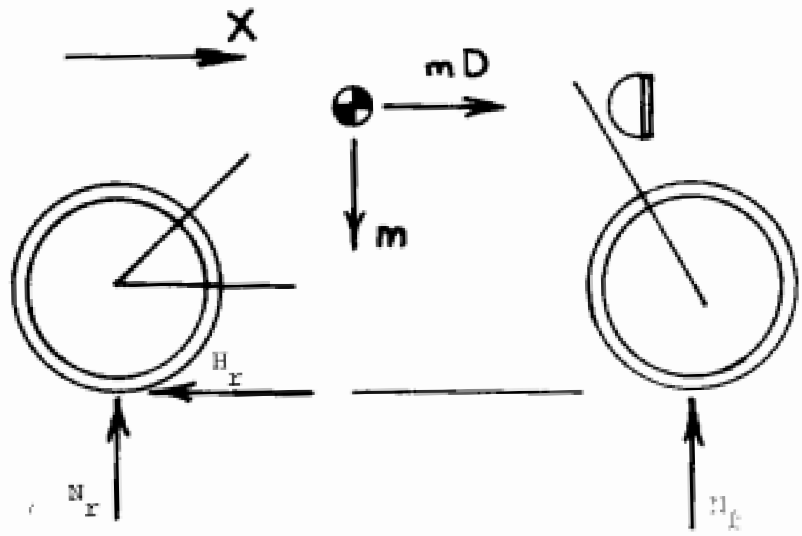

Figure A.3 Motorcycle with rear brakes applied.