BRAKING, STABILITY AND HANDLING OF MOTORCYCLES

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Abstract   A review of the literature relating to braking stability and handling
of motorcycles was undertaken. Evidence of relationships between
motorcycle characteristics and accidents was sought. Anecdotal
evidence of operational problems published in user magazines was
also reviewed. Experimental and analytical investigations of
motorcycle dynamics, and the effects of accessories, tyres and
machine modifications, was surveyed. Problem areas were identified
and priorities for further research recommended.

KEYWORDS: Motorcycles, Handling/Controllability/Directional Control, Vehicle Braking,
Accident Causation/Accident Patterns.

SUMMARY

This report documents the first of two phases of a research
project concerned with braking, stability and handling of
motorcycles. Phase I constituted a literature review, the
objectives of which were to review the state of knowledge,
isolate problem areas and recommend priorities for further
research. As a result of this review, a Phase II investigation
of ergonomic aspects of motorcycle braking control was initiated
and reported separately (Juniper and Good, 1983).

The accident literature demonstrated that motorcyclists are
more likely to be involved in an accident than other vehicle
users, and the consequences are more severe. In the most common
accident scenario, the motorcyle's right of way is violated by
another vehicle. The accident-avoidance capabilities of riders
and bikes are consequently of considerable importance. The
literature revealed, however, that riders typically make poor use
of the braking capacity of their machines, thereby increasing
both accident frequency and severity. The contribution of
motorcycle stability and handling characteristics to accident
risk has not been adequately determined, in part due to a lack of
knowledge of the most appropriate way to describe these
characteristics. Virtually all motorcycle accident studies have
suffered from inadequate, or a complete lack of exposure data
which would allow statistical inferences to be drawn about
vehicle-related factors in accident causation.

Other aspects of the literature review included disc brake
performance in wet weather, antilock brakes, linked brake systems
and brake modulability. Analytical and experimental
investigations of rider/cycle stability and handling were
reviewed, both for standard machines and those modified by
fitting of accessories, structural changes and the carrying of
loads.

Recommendations for futher research are made on the basis of the
problems identified in this review.

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND TO REVIEW

In its report on motorcycle and bicycle safety, the House of Representatives Standing Committee on Road Safety (HoR, 1978, Para. 81) recommended that:

> "A literature and research review of existing
> and potential problems relating to motorcycle
> stability and handling be undertaken by the
> Advisory Committee on Safety in Vehicle
> Design."

Furthermore, the committee recommended experimental appraisal of antilock and linked brake systems. They expressed concern about possible motorcycle instabilities arising through the fitment of fairings and the carrying of luggage. In addition, they said that the safety aspects of the matching of tyres to machines should be investigated.

On the basis of these recommendations the Office of Road Safety of the Australian Department of Transport commissioned a two-phase research project entitled "Braking, Stability and Handling of Motorcycles". Phase I was to be a literature and research review, while Phase II was to be an experimental investigation of a high-priority problem area revealed by the review.

This report documents the Phase I literature and research review. The Phase II investigation has been reported separately (Juniper and Good, 1983).

1.2 OUTLINE OF REVIEW

Chapter two examines the motorcycle accident literature and specifically looks for evidence of involvement of braking, stability and handling problems in accidents.

Chapter three reviews the literature specifically concerning braking aspects of motorcycles, and highlights deficiencies in motorcycle brake design and rider control problems.

Chapter four studies the literature relating to stability and handling of motorcycles. This encompasses both mathematical modelling of the rider/motorcycle system and experimental investigations aimed at quantifying the lateral dynamic behaviour and rider control of motorcycles. Anecdotal evidence of stability and handling problems from the popular press is also reviewed.

Chapter five reviews the literature which looks at the influence of accessories (such as fairings and pannier bags), tyres and machine modifications on motorcycle stability and handling.

Finally Chapter six presents conclusions and recommendations for further research arising from this literature review. It was from these recommendations that the topic for the Phase II experimental program reported in Juniper and Good (1983) was selected.

2. EVIDENCE OF RELATIONSHIPS BETWEEN MOTORCYCLE BRAKING, STABILITY AND HANDLING CHARACTERISTICS, AND ACCIDENTS

2.1 INTRODUCTION

The motorcycle accident literature was examined with a view to ascertaining the degree of involvement of braking, stability and handling characteristics in accidents. There has been no specific study aimed at isolating these factors; consequently the level of their involvement can only be inferred.

2.2 REVIEW OF ACCIDENT LITERATURE

2.2.1 Motorcycle Accident Description

Figure 2.1 shows the number of vehicles on register in Australia from 1960 to 1980. Cars and station wagons are shown separately from motorcycles. Apart from a slight downward trend in the early 1960's, the motorcycle population has consistently increased over a thirteen year period. In comparison to cars and station wagons, motorcycles use much less fuel per kilometre, require a smaller initial capital outlay, and their small size permits easy parking in crowded urban environments. Unfortunately motorcyclists are the most vulnerable of all road users in an accident, primarily because the rider is virtually unprotected (save for a helmet in Australia). The relative hazard for a motorcyclist compared to a motor car or station wagon occupant is shown in Table 2.1 (drawn from Johnston, Milne and Cameron, 1976). Relative hazard is defined as the accident rate for motorcycles divided by the accident rate for cars and station wagons. The relative hazard for the motorcyclist ranges from 2.9 to 16.4 depending on the basis for comparison. The motorcyclist is definitely at very great risk.
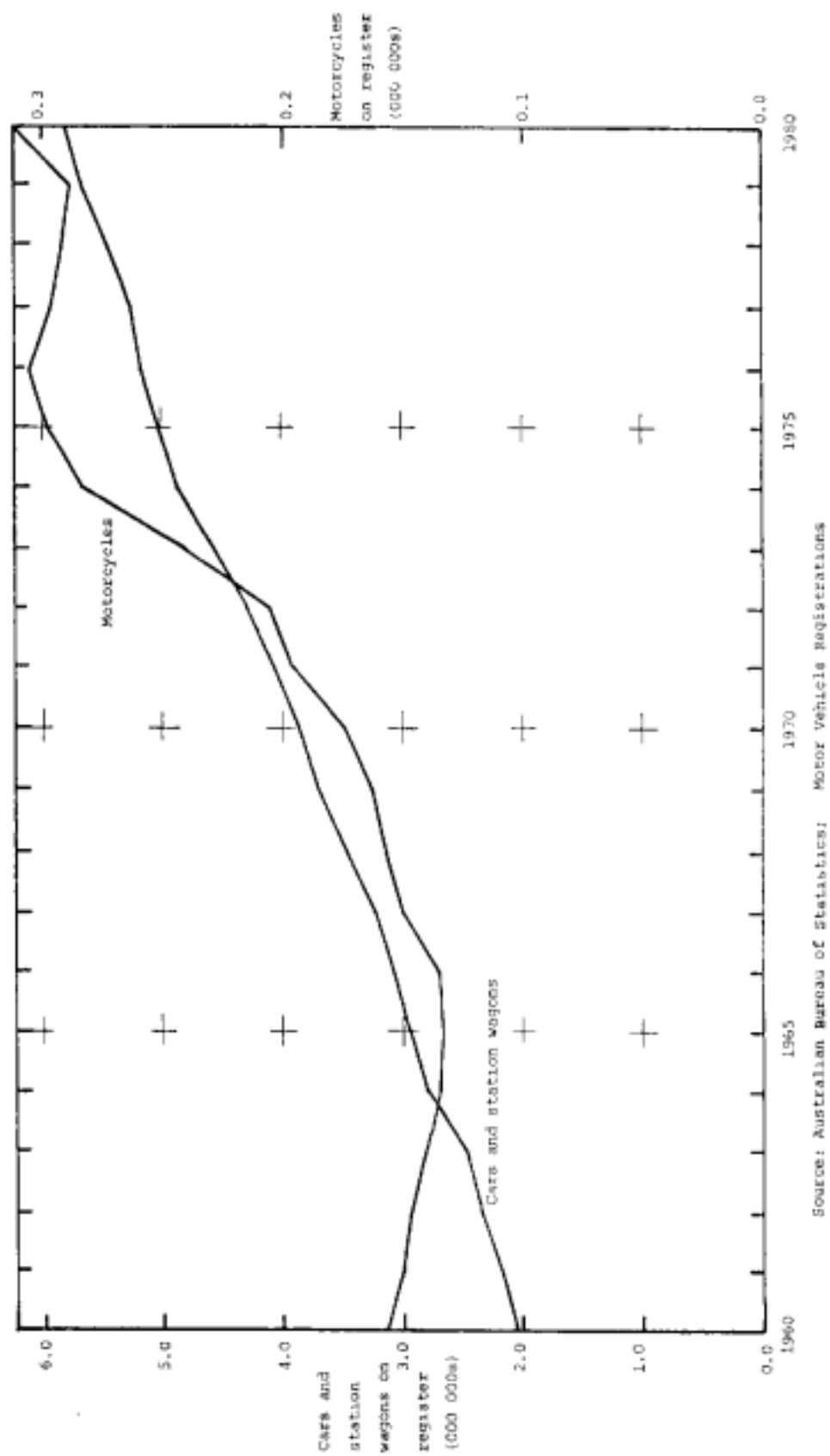
Figure 2.1 Total vehicles on register – motorcycles and cars/station wagons.

Source: Australian Bureau of Statistics: Motor Vehicle Registrations

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TABLE 2.1. RELATIVE HAZARD OF MOTORCYCLE TRAVEL COMPARED WITH
OTHER FORMS OF ROAD TRANSPORT, VICTORIA, 1971
(after   Johnston, Milne and Cameron, 1976).

	MOTOR CYCLES	CARS AND STATION WAGONS	LIGHT COMMERCIAL	TRUCKS	BUSES	TOTAL	RELATIVE HAZARD 1
Number on register	28,160	1,131,361	136,303	92,323	5,129	1,393,276	
Vehicle kilometres (million)	195.8	18,649.3	2,086.7	1,862.9	132.7	23,062.3	
Occupant kilometres (million)	192	36,225	2,737	2,254	1,327	42,734	
Involvement in casualty accidents	1,333	18,794	1,650	1,246	94	23,117	
Occupant casualties	1,350	15,626	1,219	315	90	18,600	
Accidents per '000 vehicles	47.34	16.61	12.11	13.50	18.32	16.59	2.9
Accidents per million vehicle km's	7.17	1.00	0.79	0.67	0.71	1.00	7.2
Accidents per million occupant km's	6.96	0.52	0.60	0.55	0.07	0.54	13.4
Casualties per '000 vehicles	47.94	13.81	8.94	3.41	17.55	13.35	3.5
Casualties per million vehicle km's	7.27	0.84	0.58	0.17	0.68	0.81	8.7
Casualties per million occupant km's	7.04	0.43	0.45	0.14	0.07	0.43	16.4

Notes: 1.   Relative hazard = $\dfrac{\text{Rate for motorcycles}}{\text{Rate for all vehicles}}$

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The typical motorcycle accident involves a collision with another road user: a motor car in about 70% of cases. This pattern is almost universal (Henderson, 1970; Herbert and Corben, 1977; Herbert and Humphreys, 1978 a and b, 1979; Honda, 1977; Hurt, Ouellet and Thom, 1981; Inayoshi, 1973; McLean, Brewer, Hall, Sandow and Tamblyn, 1979; Messiter, 1972; Newman, 1976; Reiss, Berger and Vallette, 1974; Vaughan, Pettigrew and Lukin, 1977; Waller, 1972; Whitaker, 1976; White, 1978). Furthermore White (1978) found that the motorcycle is most often travelling straight when struck by another vehicle (Figure 2.2), that the other vehicle is frequently turning across the motorcycle path (Table 2.2), and that the motorcycle is the striking vehicle two thirds of the time, as the front of the motorcycle is the impact point in 60% of accidents with other motor vehicles, 70% of accidents with fixed objects, and 55% of accidents with pedestrians (Figure 2.3). McLean et al.(1979) found that in 26% of accidents a vehicle turned across the path of the motorcycle, and Hurt et al. (1981) indicated 33.5% of this type. In the study by Hurt et al.(1981) the most frequent accident scenario involved the motorcycle travelling straight and the motor car making a left turn in front of the oncoming motorcycle. This occurred in 26.7% of the 900 accidents studied, and 33.4% of the multiple-vehicle collisions. The equivalent accident type in Australia would be the motor car making a right turn across the motorcycle path, as Australians travel on the left side of the roadway. Newman (1976) found that 23.5% of all accidents involving motorcycles occurred at right-angle intersections, and 19% of all motorcycle accidents were accounted for by a vehicle turning across the path of the motorcycle.

The motorcyclist is usually not to blame when involved in a collision with another vehicle. McLean et al. (1979) declared that in 78% of multi-vehicle motorcycle accidents studied the other vehicle should have yielded. White (1978) affirmed that for the two-vehicle accidents analyzed, police laid charges against 60% of the vehicle drivers. Barry (1970) found that the
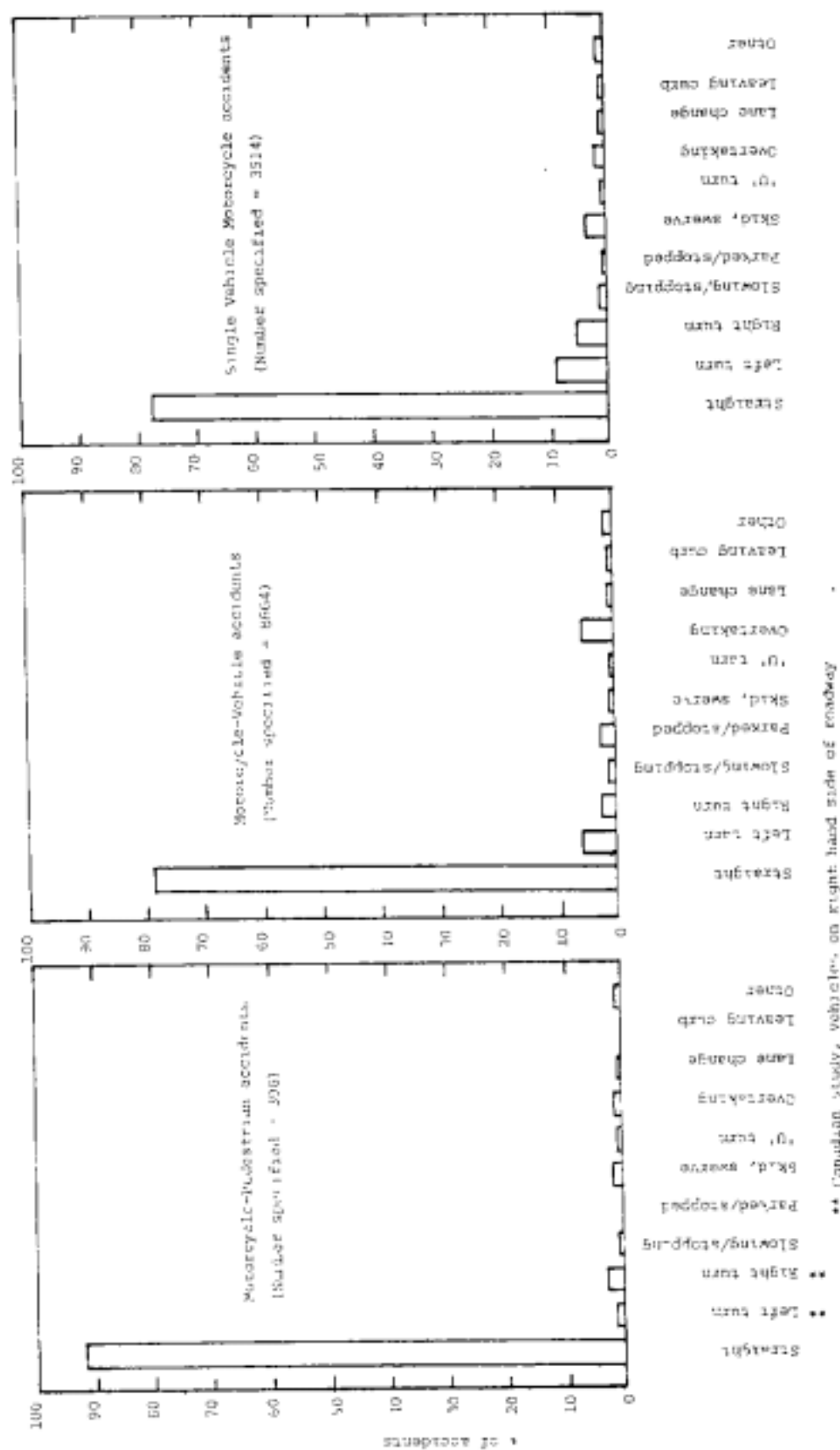
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driver of the other vehicle was charged in 52% of the crashes, and suggested that in two-vehicle crashes, it is most frequently the motorist who is guilty of a violation. Figure 2.4 shows a culpability assessment of motorcycle involved accidents for Maryland (U.S.A.), due to Reiss et al. (1974).

Motorcycle accidents are generally located in urban/suburban areas. Hurt et al. (1981) studied a total of 900 motorcycle accidents in an area consisting of a wide variety of urban, suburban and rural regions, and 90% of the accidents occurred in the urban/suburban area. For the state of Victoria, 1976, 58% of fatal motorcycle-involved accidents occurred within Metropolitan Melbourne, and 64% of injury motorcycle-involved accidents occurred in this area (Australian Bureau of Statistics, 1976). Henderson (1970), in a study of 120 fatalities in New South Wales, indicated that 78% happened on roads within the 60 km/h speed limit applying to built up areas. Foldvary (1973) analyzed accident statistics for the state of Victoria collected in 1961, and reported that 71% of motorcycle accidents occurred in the Metropolitan area. Reiss et al. (1974) studied 1191 motorcycle accidents in 1973 in Maryland (U.S.A.), of which 70% occurred within urban area.

Under wet road conditions, it might be expected that motorcycles would be at greater risk of accident involvement. Carraro (1978) claimed that the majority of motorcycle accidents (84% to 96%) occur on dry roads. Reiss et al. (1974) affirmed that 91% of motorcycle accidents were in dry conditions, and Hurt et al. (1981) found adverse weather was not a factor in the majority of accidents; less than 3% involved wet roads. Hurt claimed that motorcycle traffic essentially disappears in adverse weather. However, for the motorcycle traffic that is on the roads, risks are increased. To assess the effects of wet weather, the proportion of the exposed population riding in these conditions which are involved in accidents is required. As an example, Watson and Lander (1974) found that 30% of 120 accidents

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TABLE 2.2. VEHICLE DIRECTION OF TRAVEL IN TWO VEHICLE ACCIDENTS (White, 1978).

Motorcycle Direction of Travel	Going Straight	Overtaking	Left Turn	Right Turn	U-turn	Lane Change	Merge	Reverse	Stopped	Pulling Away From Curb	Pulling Into Curb	Total Spec.
Going Straight	486	19	567	68	16	42	9	18	88	15	2	1330
%	(24.5)	(1.0)	(28.6)	(3.4)	(0.8)	(2.1)	(0.5)	(0.9)	(4.4)	(0.8)	(0.1)	(67.1)
Overtaking	31	3	111	17	2	4	0	1	9	1	2	181
%	(1.6)	(0.2)	(5.6)	(0.9)	(0.1)	(0.2)		(0.1)	(0.5)	(0.1)	(0.1)	(9.1)
Left Turn [1]	232	28	11	3	0	0	0	0	3	2	0	279
%	(11.7)	(1.4)	(0.6)	(5.2)					(0.2)	(0.1)		(14.1)
Right Turn [1]	34	10	1	4	0	1	0	1	2	0	0	53
%	(1.7)	(0.5)	(0.1)	(0.2)		(0.1)		(0.1)	(0.1)			(2.7)
U-Turn	7	1	0	0	0	0	0	0	0	0	0	8
%	(0.4)	(0.1)										(0.4)
Lane Change	12	2	4	2	0	1	0	0	1	0	0	22
%	(0.6)	(0.1)	(0.2)	(0.1)		(0.1)			(0.1)			(1.1)
Merge	7	1	0	0	0	0	0	0	0	0	0	8
%	(0.4)	(0.1)										(0.4)
Reverse	9	0	0	0	0	0	0	0	2	0	0	11
%	(0.5)								(0.1)			(0.6)
Stopped	58	5	2	0	0	3	0	1	0	0	0	69
%	(2.9)	(0.3)	(0.1)			(0.2)		(0.1)				(3.5)
Pulling Away From Curb	11	0	0	0	0	0	0	0	1	0	0	12
%	(0.6)								(0.1)			(0.6)
Pulling Into Curb	4	4	0	0	0	0	0	0	0	0	0	8
%	(0.2)	(0.2)										(0.4)
Total Spec.	891	73	696	94	18	51	9	21	106	18	4	1981
%	(45.0)	(3.7)	(35.1)	(4.7)	(0.9)	(2.6)	(0.5)	(1.1)	(5.4)	(0.9)	(0.2)	(100.0)

Note: 1. Canadian study, vehicles travel on right side of roadway.
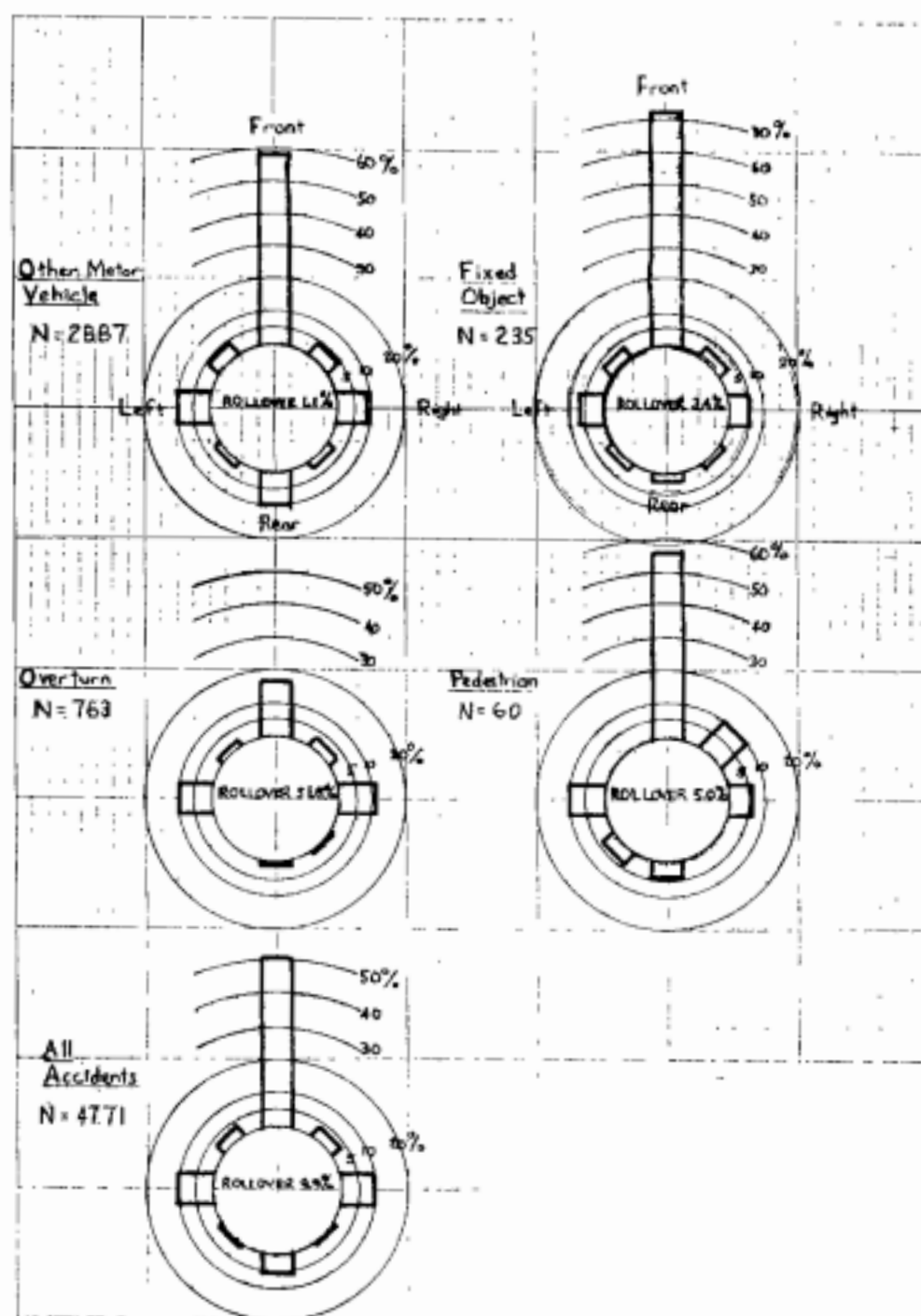
Figure 2.3. Motorcycle impact point distribution for selected
accident types (White, 1978).

CULPABILITY	TYPE 1 URBAN/INT	TYPE 2 URBAN/NON-INT	TYPE 3 RURAL/INT	TYPE 4 RURAL/NON-INT
MDAI	O/V OPER= 100% M/C OPER= 0% (N= 16)	O/V OPER= 40% M/C OPER= 60% (N= 5)	O/V OPER= 0% M/C OPER= 100% (N=1)	O/V OPER= 29% M/C OPER= 71% (N= 7)
MD	O/V OPER= 69% M/C OPER= 29% JOINT 2% (N= 100)	O/V OPER= 49% M/C OPER= 49% ENVIRON= 1% M/C DEFECTS= 1% (N= 100)	O/V OPER= 72% M/C OPER= 27% M/C DEFECTS= 1% (N= 100)	O/V OPER= 45% M/C OPER= 41% ENVIRON= 11% JOINT (M/C&O/V)=3% (N= 100)

MDAI = Multi-Disciplinary Accident Investigation data

MD   = Maryland Accident Data (U.S.A.)

O/V OPER = Other Vehicle Operator

M/C OPER = Motorcycle Operator

Figure 2.4   Comparison of accident culpability (Reiss, Berger and Vallette, 1974)

investigated by an on-the-spot investigation team in the U.K. occurred when the road was wet. They concluded that as roads are wet for one day in five (20%), the motorcycle is more accident-prone when the road is wet.

2.2.2   Braking Behaviour and Accidents

A motorcycle is very sensitive to the braking procedures employed by the rider. An erroneous braking manoeuvre can result in loss of control and consequently a spill. If the rider locks the rear wheel, the machine can slide out sideways, and unless the motorcyclist is skilled in handling this situation, a fall will result. A front wheel lock up will almost always result in the motorcycle capsizing, even in the hands of a skilled operator.

Table 2.3, from Watson and Lander (1974), shows that in dry conditions motorcyles are 1.22 times more liable to skid prior to an accident than other vehicles, and 1.69 times more liable in wet conditions. Under ice and snow conditions skidding is a problem with all vehicles, as the friction coefficient is then very low.

Inayoshi (1973) reported that in accidents where a motorcycle collided with another vehicle, the rider used the front and rear brakes together on 39.9% of occasions, front brake alone on 3.2%, and rear brake alone on 18.2%. He further stated that for single-vehicle accidents, the rider used front and rear brakes 28.8% of times, front brake alone 4.2%, and rear brake alone 13.4%. Table 2.4, reproduced from Hurt (1979), shows similar proportions for brake usage. It is seen that in accidents the front and rear brakes were used together in 24.8% of cases, front brake alone in 0.9%, and rear brake alone in 26.7% of cases.

McLean et al. (1979) found that front and rear brakes were applied in 19% of accidents studied, 6% used front only and 20% used the rear brake alone. Furthermore, experienced riders were

TABLE 2.3 SKIDDING IN PERSONAL-INJURY ACCIDENTS IN GREAT BRITAIN - 1972 (Watson and Lander, 1973).

	DRY			WET			ICE/SNOW			ALL CONDITIONS		
	Skidded	Total	%	Skidded	Total	%	Skidded	Total	%	Skidded	Total	%
MOTORCYCLES	4 147	37 824	11	3 432	12 957	27	568	1 019	56	8 147	51 800	16
OTHER VEHICLES	20 423	229 645	9	19 256	117 221	16	8 531	17 427	49	48 210	364 293	13

TABLE 2.4 COMPARISON OF FRONT AND REAR BRAKE USE IN COLLISION AVOIDANCE (Hurt, 1979).

(Rear Brake)

(FRONT BRAKE)	COUNT ROW PCT COL PCT TOT PCT	Not Equipped 0.	Equipped But Not Operational 1	Operational But Not In 2.	In At Accident 3.	Unable To Determine if on at Time of Accident 5	ROW TOTAL
Not Equipped	0.	1 4.2 100.0 0.1	0 7.0 0.0 0.0	10 41.7 1.8 1..	13 54.2 2.5 1.3	0 0.0 0.0 0.0	24 2.7
Equipped but Not Operational	..	0 0.0 0.0 0.0	0 0.0 0.0 0.0	14 28.8 3.9 1.6	22 61.1 4.3 2.5	0 0.0 0.0 0.0	36 4.0
Operational But Not In	2.	0 0.0 0.0 0.0	5 0.8 20.0 2.1	322 57.1 90.4 36.3	233 41.4 46.8 26.7	1 0.4 3.1 0.2	564 62.3
On At Accident	3.	0 0.0 0.0 0.0	4 1.7 80.0 7.4	5 2.4 2.6 0.5	222 94.3 43.4 24.9	0 0.0 0.0 0.0	234 26.1
Equipped Unable To Determine if Operational	4.	0 0.0 0.0 0.0	0 0.0 0.0 0.0	2 40.0 0.5 0.2	1 20.0 0.2 0.1	2 40.0 9.1 0.2	5 0.6
Unable To Determine if on at Time of Accident	5.	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	14 43.8 2.7 1.6	18 56.2 81.8 2.0	32 3.6
	COLUMN TOTAL	1 0.1	5 0.6	358 39.8	511 57.1	22 2.5	895 100.0

just as likely to fail to make full use of the braking potential of their machine (by using the rear brake only) as those who were relatively inexperienced. It should be noted that using the rear brake only significantly degrades the collision-avoidance performance of a motorcycle.

Wilkins (1969) estimated that in 5% of 140 accidents studied, the rider was thrown off as a result of wheel locking due to braking. Wilkins also stated that a further 50% would possibly not have occurred if the motorcycle brakes had been more efficient or had been applied earlier.

2.2.3 Stability and Motorcycle Accidents

A motorcycle has only two wheels and may be inherently unstable. In the absence of rider input and corrections the machine may ultimately capsize. A motorcycle under certain conditions will exhibit uncontrollable vibration behaviour. The characteristic modes of these vibrations are well documented. There are three dominant modes: (i) wobble, a high speed phenomenon consisting primarily of an oscillation of the steering assembly, (ii) weave, a coupled yaw, roll, steer oscillation which is usually well damped at medium speeds and lightly damped at low and high speeds, and (iii) capsize, an aperiodic motion, which is usually stable at low speed, and slightly unstable at medium and high speeds (Eaton, 1973; Roe and Thorp, 1976; Sharp, 1971; Weir, Zellner and Teper, 1978, Koenen and Pacejka, 1980).

(a) Loss of control

There is little evidence of stability problems in the accident literature. The relationship between motorcycle dynamic behaviour and accidents has still to be established. Identifying the contributing characteristics in accident causation would be a very difficult task. The greater proportion of accidents occur in urban areas with speed

TABLE 2.5 LOSS OF CONTROL MADE IN A MOTORCYCLE ACCIDENT
STUDY (Hurt, 1979).

CATEGORY LABEL		ABSOLUTE FREQ.	RELATIVE FREQ.%	ADJUSTED FREQ %
		2	0.2	0.6
Capsize		42	4.7	11.7
Wobble		5	0.6	1.4
Weave		2	0.2	0.6
Lost Wheelie		9	1.0	2.5
Slide Out		202	22.5	56.2
High Side		19	2.1	3.3
Wide in Turn		77	8.6	21.4
End Over		1	0.1	0.3
Unknown		4	0.4	MISSING
N A		536	59.6	MISSING
	TOTAL	899	100.9	100.0

TABLE 2.6 RELATIVE INVOLVEMENT OF PILLION PASSENGERS IN
MOTORCYCLE ACCIDENTS (Vaughan, Pettigrew and
Lukin, 1977).

Road Users riding motorcycles, by class	Motorcycles in the Sydney Metropolitan Area – Level Two Study			
	Observed in Surveys (%)		Involved in Crashes (%)	
Riders	1 305	(94%)	967	(91%)
Pillion passengers	76	(6%)	97	(9%)
TOTAL	1381	(100%)	1064	(100%)

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TABLE 2.7 TYRE QUESTIONNAIRE RESPONSES (House of Representatives
Standing Committee on Road Safety, 2 October 1979).

M.   R.   A.
MOTORCYCLE RIDERS' ASSOCIATION
P.O. BOX 238, PADDINGTON, QLD..4064

TYRE SURVEY

Questions	Yes	No	Unsure
Have you had an accident because of a tyre/tyres?	33%	67%	
Are you satisfied with the standard tyres as fitted to new motorcycles?	20%	69%	11%
Should there be standards for tyres?	81%	14%	5%
Is there enough information readily available to enable you to choose correctly the tyres for your bike?	21%	78%	1%
Where does most of your information on tyres come from eg. friends, magazines, bike shops etc?	Friends		42%
	Magazines		32%
	Bike Shops		9%
	Experience		14%
	Others		3%
Do you feel you know enough to choose a tyre correctly?	63%	33%	4%
Do you think there are sub-standard tyres available?	90%	4%	6%
Do you think tyres are too expensive?	78%	18%	4%
Do you think tyres last long enough?	47%	48%	5%

The above questions were put to people at random,
visiting motorcycle retailers in Brisbane on the
16th June, 1979.

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limits less than 60 km/h, whereas the unstable weave and wobble modes are not normally excited at speeds less than 100 km/h. However there are a few cases reported. For example, Herbert and Corben (1977) and Herbert and Humphries (1978 a and b, 1979) reported that in 3 of 100 accidents studied, wobble was a casual factor. Table 2.5 gives a breakdown of the types of loss of control in motorcycle accidents (Hurt, 1979). Loss of control due to the motorcycle instabilities capsize, wobble and weave together account for 5% of the accidents studied. Newman (1976) reported general loss of control in 8% of accidents (without further clarification).

(b) Pillion passengers

Waller (1972) said that pillion passengers figured more heavily in single-vehicle accidents than in multi-vehicle accidents (15% compared with 11%). Such passengers were also present in 60% of accidents caused by blowouts. Table 2.6, extracted from Vaughan, Pettigrew and Lukin (1977), indicates that a motorcycle is at 1.66 times the average risk of being involved in an accident when carrying a pillion passenger. Hurt et al. (1981) however, found that whereas passengers were involved in 17.1% of the 899 accidents analyzed, and in 14.8% of 3622 cases examined from traffic accident reports, exposure data showed that passenger-carrying motorcycles were 18.3% of the population at risk. This implies that there was no increase in risk due to the presence of a passenger.

(c) Tyres

Table 2.7 shows the results of a questionnaire organized by the Motorcycle Riders' Association, Queensland (House of Representatives Standing Committee on Road Safety, 1979). Thirty-three percent of respondents (sample size not known)

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TABLE 2.8 CONTRIBUTORY TYRE CONDITIONS (Hurt, 1979).

CATEGORY LABEL	CODE	ABSOLUTE FREQ.	RELATIVE FREQ.%	ADJUSTED FREQ.%	CUMULATIVE FREQ.%
Contributory Front Tire Condition					
None		855	95.1	95.1	95.1
Puncture Flat		3	0.3	0.3	95.4
Blowout		1	0.1	0.1	95.6
Worn Smooth		4	0.4	0.4	96.0
Low Pressure		22	2.4	2.4	98.4
High Pressure		9	1.0	1.0	99.4
Other		2	0.2	0.2	99.7
		2	0.2	0.2	99.9
		1	0.1	0.1	100.0
	TOTAL	899	100.00	100.00	
Contributory Rear Tire Condition					
None		834	92.8	92.9	92.9
Puncture Flat		12	1.3	1.3	94.1
Blowout		1	0.1	0.1	94.2
Worn Smooth		11	1.2	1.2	95.4
Low Pressure		22	2.4	2.4	97.9
High Pressure		12	1.3	1.3	99.2
Valve Failure		1	0.1	0.1	99.3
Other		5	0.6	0.6	99.9
		1	0.1	0.1	100.0
	TOTAL	899	100.0	100.0	

indicated they had had an accident because of tyre problems.
Table 2.8 from Hurt (1979) displays the contribution to
accidents caused by the condition of the front and rear
tyres. The most common fault was low pressure in the front
(2.4%) and rear tyres (2.4%). However these figures are
meaningless without proper exposure data. Furthermore the
effect of low pressure on the dynamic behaviour needs to be
quantified. Hurt also found puncture flats totalled 1.3% of
accidents for the rear tyre and 0.3% for the front tyre.
Puncture flats for the rear tyre were most common when the
motorcycle was carrying a passenger. Godley (1972) in an
analysis of burst tyres prior to injury accidents on the M1
and M4 motorways in the U.K. found that motorcycles had the
highest proportion of burst tyre, being 36% (the smallest
proportion was lorries at 0.3%). Figure 2.5, drawn from an
in-depth analysis of accidents (Herbert and Corben, 1977,
Herbert and Humphries, 1978 a and b, 1979), shows that the
lack of proper maintenance of tyres was considered to be the
main contributing factor in only 2 of 100 cases (2%) and of
secondary influence in 7% of cases. (66 accidents only are
represented by the causal factors shown in Figure 2.5)

2.2.4 Handling and Accidents

The role of motorcycle handling in accidents is little
understood. Suitable parameters to quantify desirable handling
characteristics have yet to be determined, though some
preliminary work has been done in this direction (Weir, Zellner
and Teper, 1978; Chenchanna and Koch, 1979). The influence of
handling characteristics on accidents cannot be ascertained until
they are well defined and measurable.

  (a) Running wide on a turn

  The most common accident in which handling may be directly
  involved is running wide on a turn. Honda (1977) reported

that running off roads in single-vehicle accidents occurred in about 9% of cases. The typical rider error in single-vehicle accidents is running wide on a corner due to excess speed or undercornering (Hurt, 1979).

Handling may play a greater role in high speed non-urban accidents. However few data are available on this type of accident.

(b) Familiarity with the motorcycle

White (1978) found that non-owners were over-represented in single-vehicle accidents, as is seen in Table 2.9.

In single-vehicle accidents, a disproportionate number of borrowers were involved in turning manoeuvres. The data indicated that 18% of the borrower's single-vehicle crashes occurred in this manner (Barry, 1970). This difference is thought to reflect the borrower's relative lack of skill with the vehicle, or his unfamiliarity with the handling behaviour of the machine.

(c) Machine modifications

A motorcyle's dynamic behaviour is sensitive to the mechanical condition of the wheel bearings, steering head bearings, wheel alignment, tyre pressure, condition and design, amount of luggage carried and the presence of a windshield or fairing. It might be expected that modified motorcycles would be over-represented in motorcycle accidents. Hurt, Ouellet and Thom (1981) collected data on machine modifications for accident-involved motorcycles, and for the total motorcycle population. These results are presented in Table 2.10, together with calculated 'relative risks'. Relative risk (RR) is the proportion of motorcycles in the accident sample with a given modification divided by
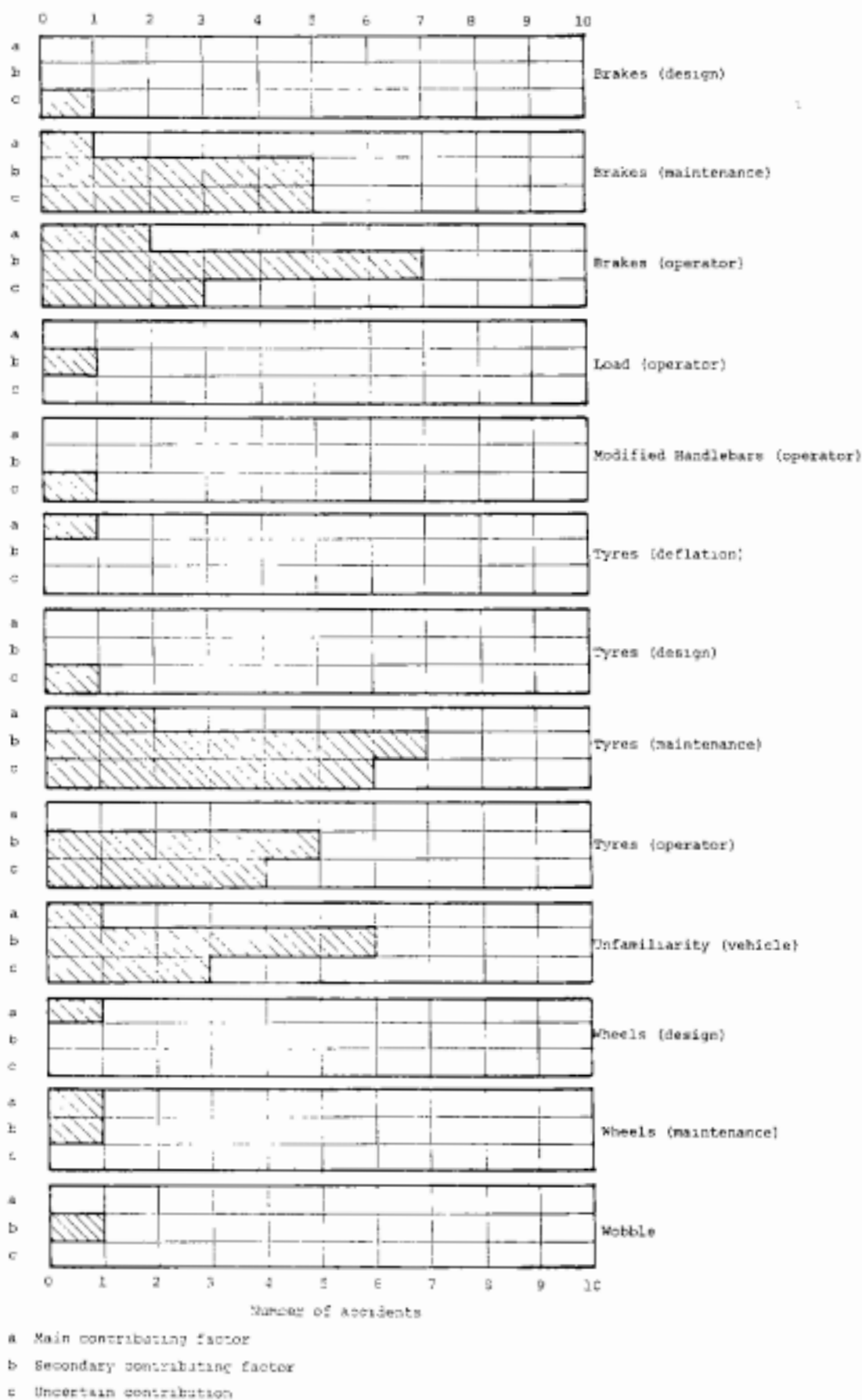
Figure 2.5   Causal factors in accidents (source: Herbert and Corben,1977,
Herbert and Humphries,1978 a and b, 1979).

TABLE 2.9   ACCIDENT-INVOLVED MOTORCYCLE OWNERSHIP (drawn from
             White, 1978)

| Accident type | Owner of motorcycle | | | Total | % total |
	Driver	Other Person	Company	Specified	
Single-vehicle	710	159	47	916	25
% col total	24	30	40		
Vehicle-vehicle	1961	315	59	2335	64
% col total	65	59	50		
Other	330	58	12	400	11
% col total	11	11	10		
Totals	3001	532	118	3651	100

TABLE 2.10   COMPARISON OF MOTORCYCLE MODIFICATIONS FOR ACCIDENT
             AND EXPOSURE DATA (drawn from Hurt et al.,1981)

Motorcycle Modification	Exposure Data %	Accident Data %	Relative Risk	Std. Dev. of estimate
Front Suspension	10.6	10.2	0.96	0.11
Rear Suspension	14.1	19.1	1.35	0.12
Crash Bars	18.1	18.1	1.0	0.08
Sissy Bars	29.8	27.1	0.91	0.06
Seat	23.1	24.8	1.07	0.07
Windshield (with or without fairing)	19.5	12.0	0.62	0.06
Fairing	12.3	8.7	0.71	0.09
Handlebars	24.8	16.3	0.66	0.06
Exhaust System	27.3	30.1	1.10	0.07

Relative Risk = relative risk of being involved in an accident
                given that motorcycle modification

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the proportion of the total population with that modification. RR thus measures the average risk associated with a given modification relative to the average risk for all motorcycles in the population (for which RR = 1). An RR of unity means that the motorcycle has an 'average' probability of being involved in an accident; an RR greater than unity implies above average accident probability; less than unity, below average (Fox, Good and Joubert, 1979 presented a useful discussion of the use of the relative risk concept). Table 2.10 also shows the standard deviation of the estimate of RR. The range RR $\pm$ SD represents approximately the 68% confidence interval for the calculated RR. From Table 2.10 it is seen that front suspension modifications (which include extended front forks) have little effect on accident involvement. However rear suspension modifications (stated as including installation of a large rear tyre and modified shock absorbers; but unfortunately no further details are given) resulted in the motorcycle having a relative risk of 1.35 $\pm$ 0.12, a significant ($p < 0.001$) departure from the average value of 1. The addition of a windshield and a fairing reduced the relative risk to 0.62 $\pm$ 0.06 and 0.71 $\pm$ 0.09 respectively. This modification is known in some cases to degrade the handling characteristics, particularly if the windshield is mounted directly to the forks of the motorcycle (Weir et al., 1978). The reduction of accident involvement may be related to the increased frontal area which improves conspicuity of the machine. McLean et al. (1979) found that alterations to the front suspension and to the handlebars were the most common modifications in their accident sample. They reported there were no accidents in which a rider was obviously disadvantaged by either extended forks or modified handlebars. Table 2.11 (Kraus, Riggins, Drysdale and Franti, 1973) shows an accident sample and a comparison group sample for vehicle modifications together with their relative risks, as defined above. There appears to be no significant change in risk resulting from the modifications.

TABLE 2.11   RELATIVE RISK OF MOTORCYCLES WITH MODIFICATIONS
(drawn from Kraus et al., 1973)

Type of Motorcycle Modification	Case Group		Comparison Group		Relative Risk	Std. Dev. of estimate
	No.	%	No.	%		
Modified engine	73	9.7	55	12.6	0.77	0.13
Front fork extended (250 mm)	39	5.2	19	4.3	1.19	0.33
Front fork extended (250 mm +)	20	2.7	13	3.0	0.89	0.31
Raised foot rests	31	4.1	23	5.3	0.78	0.21
Lowered seat	38	5.1	27	6.2	0.82	0.20
Modified handlebars	66	8.8	41	9.4	0.94	0.18
Sissy bar	38	5.1	37	8.5	0.60	0.13
Other modifications	42	5.6	52	11.9	0.47	0.09
No modifications	546	72.6	312	71.4	1.02	0.04
No. of respondents	752	100.0	437	100.0		

Relative Risk = relative risk of being involved in an accident
given that motorcycle modification.

2.3   CONCLUSIONS

(i)   Approximately 75% of motorcycle accidents, and 70% of casuality accidents occur in the urban/suburban area where the speed limit is 60 km/h.

(ii)   The most common motorcycle accident involves a collision with another motor vehicle (70% of cases)

(iii)   With motorcycle-vehicle collisions, the other vehicle typically turns across the path of the motorcycle. This accident type is represented in about 30% of motorcycle-vehicle collisions.

(iv)   When blame is apportioned for motorcycle-vehicle collisions, the driver of the other vehicle is usually responsible (60% of cases).

(v)   When a motorcyclist brakes to avoid a collision the full braking potential of the machine is typically not realized. Front and rear brakes were used together in only about 25% of the accidents studied by Hurt (1979). If one brake alone is used, the deceleration of the motor-cycle is reduced considerably, resulting in a higher impact speed and increased crash severity than if both brakes had been used.

(vi)   Motorcycles that are on the road in wet weather have an increased chance of being involved in an accident. However wet weather does not appear to be a problem, as between 91% to 97% of accidents occur on dry roads. Apparently motorcycle traffic essentially disappears in wet weather.

(vii)   There is little evidence of stability problems in accidents. This is probably due to the low speed at which most accidents occur (less than 60 km/h). There have been some isolated cases reported in which the motorcycle instabilities capsize, weave and wobble were involved (3% to 5%).

(viii) The literature relating to pillion passengers and accident involvement offer conflicting views. Vaughan et al. (1977) found that a motorcycle with a pillion passenger had 1.66 times the average risk of being in an accident. On the other hand, the study by Hurt et al. (1981) shows no increase in risk due to the presence of a passenger. Barry (1972) found that pillion passengers figured more heavily in single-vehicle accidents than multi-vehicle accidents.

(ix)   With regard to motorcycle tyres, one study found that motorcycles had the highest proportion of burst tyres prior to an injury accident on the M1 and M4 motorways in the U.K. Apart from this work there was little evidence to suggest that tyre pressures, condition and design were important accident causation factors.

(x)   In single-vehicle accidents, the most common handling problem found in the accident literature was running wide on a turn.

(xi)   Borrowers are more involved in single-vehicle accidents than in multi-vehicle accidents. This may be due to unfamiliarity with the borrowed motorcycle's handling behaviour.

(xii) Modifications to motorcycles do not have a great influence on accident involvement. In one study, however, rear suspension modifications were found to result in a relative risk of 1.35 ± 0.12.

3. MOTORCYCLE BRAKING

3.1 INTRODUCTION

A conclusion from Chapter 2 is that there is evidence of braking problems in accidents. Such problems were related to rider strategy in decelerating the motorcycle when trying to avoid an accident. In-depth accident studies revealed that motorcyclists used both brakes together in only half of the accidents in which braking was attempted. Inability to use both brakes means that the motorcycle does not decelerate at its maximum rate. If both brakes were used, some accidents might have been avoided, and the severity of others could have been reduced.

Following is a review of the literature specific to motorcycle brakes and associated problems.

3.2 MOTORCYCLE BRAKES AND PROBLEM AREAS

3.2.1 Disc Brake Performance In Wet Weather

Motorcycles today are almost universally fitted with disc brakes as original equipment. Disc brakes give the motorcycle the potential to stop rapidly in dry conditions. Furthermore it is only under race conditions that disc brakes will exhibit fade problems (temperature induced loss of effectiveness). Their response to rider input is both predictable and controllable, which could explain motorcyclists' preference for this system. They are a low maintenance device and their appearance is aesthetically pleasing. However their performance suffers considerably in wet conditions. The House of Representatives Standing Committee on Road Safety (HoR, 1978) said in paragraphs 65 and 67 of their report:

65. The deterioration in braking performance of disc brakes in wet weather is of concern and the Committee was informed that Japanese manufacturers are research- ing various ways to solve the problem. Research has indicated that mechanical sources of improving wet weather braking performance are the material of the disc and the pad.

67. Several witnesses referred to long delays in effective braking with several makes of front disc brakes in wet conditions. . .

Irving (1978) referred to the increased response time of a wet disc brake after traversing a deep water splash. Initially on application of the brake lever, very little braking effect is felt, as a film of water exists between the disc and the pad. Then due to centrifugal effects of the rotating disc and the scraping action of the pads, the disc dries, and suddenly a large braking torque appears with possible disastrous results.

The Transport and Road Research Laboratory (TRRL, 1978 a) indicated that riders experience significant and inconsistent reductions in wet braking efficiency. Their research has shown that the reduction in braking efficiency is caused by the presence of a laminar layer of water on the surface area of the disc acted on by the pads. Any excess water beyond that necessary to form the laminar layer is in the form of a turbulent layer. This layer does not affect the brake performance directly, but acts as a reservoir to maintain the laminar sublayer. Robinson (1978 a and b) using an experimental laboratory disc brake dynamometer confirmed the increase in stopping time attributable to a wet disc. Using the same brake line pressures, the wet disc took between two and three times as long to stop as a dry disc.

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As well as an increased response time for a wet disc, the level of force input from the rider to obtain a brake torque similar to that for a dry disc is increased by a factor of approximately two. Work at Honda Research and Development, Japan, reported by Wigan (1977) has shown that the rider needs to apply double the pressure on the disc brake lever in wet conditions — a reaction which many experienced motorcyclists find very difficult as a result of their trained reactions linked to dry conditions. Figure 3.1 shows these disc brake characteristics schematically. TRRL leaflet LF697 (1978 a) stated that riders are not able to judge the amount of brake application pressure required to provide a desired level of deceleration and because the road surface is also wet, overbraking can lead to wheel locking and loss of control.

It would appear that a solution to wet weather disc brake performance might be available, based on experimental work at TRRL with sintered metal disc pads. The performance of such pads in dry conditions is equal to that of organic pads. They give adequate wear rates, and the stopping distances when the discs are wet are little different from that when dry, as is indicated by Figure 3.2. However problems have been encountered with boiling brake fluid, and crazing of hard-chromed cast iron discs. These problems can be overcome by using a special hydraulic fluid, insulating the sintered pads from the wheel cylinder piston, and using stainless steel discs. These factors will make it difficult for sintered pads to be generally available as a change-over item for existing motorcycles, but manufacturers could be encouraged to market them on new machines.

3.2.2   Australian Design Rule Number 33 – Motorcycle and Moped Braking Systems

The Australian Transport Advisory Council has recommended to Commonwealth and State Governments that all motorcycles and mopeds manufactured on and after 1 March 1976 should comply with

Australian Design Rule No. 33 - Motorcycle and Moped Braking Systems. (Department of Transport, 1980). Aspects of the testing procedure in this design rule are considered to be inadequate as discussed below. ADR 33 is closely modelled on the American Federal Motor Vehicle Safety Standard (FMVSS) No. 122 (U.S. D.O.T., 1977-78) and some of the FMVSS 122 revisions have been included in ADR 33.

Ervin et al. (1977) developed a test methodology for the measurement of motorcycle braking performance. They employed a technique whereby the motorcycle was towed behind a utility truck with a torsionally-stiff tow coupling, as shown in Figure 3.3.

They began with the premise that FMVSS 122 was fundamentally inadequate in areas relating to the measurement of motorcycle braking performance, and furthermore the test rider was exposed to a potentially hazardous situation. It was demonstrated that the tow method adequately evaluates the performance of a motorcycle brake system including effectiveness, burnish, thermally induced fade and wet brake performance.

Wigan (1978) indicated two additional inadequacies of ADR 33, namely:

(i)   lack of specification of road surface condition during testing (FMVSS 122 has been amended to this end)

(ii)   the water conditioning procedure for wet brake testing does not model the real world situation accurately. ADR 33 calls for submerging the complete brake assembly in water for two minutes.

The wetting procedure makes it virtually impossible for zero-pressure-gradient seals on some drum brakes to pass the wetted brake test even though they may perform satisfactorily in
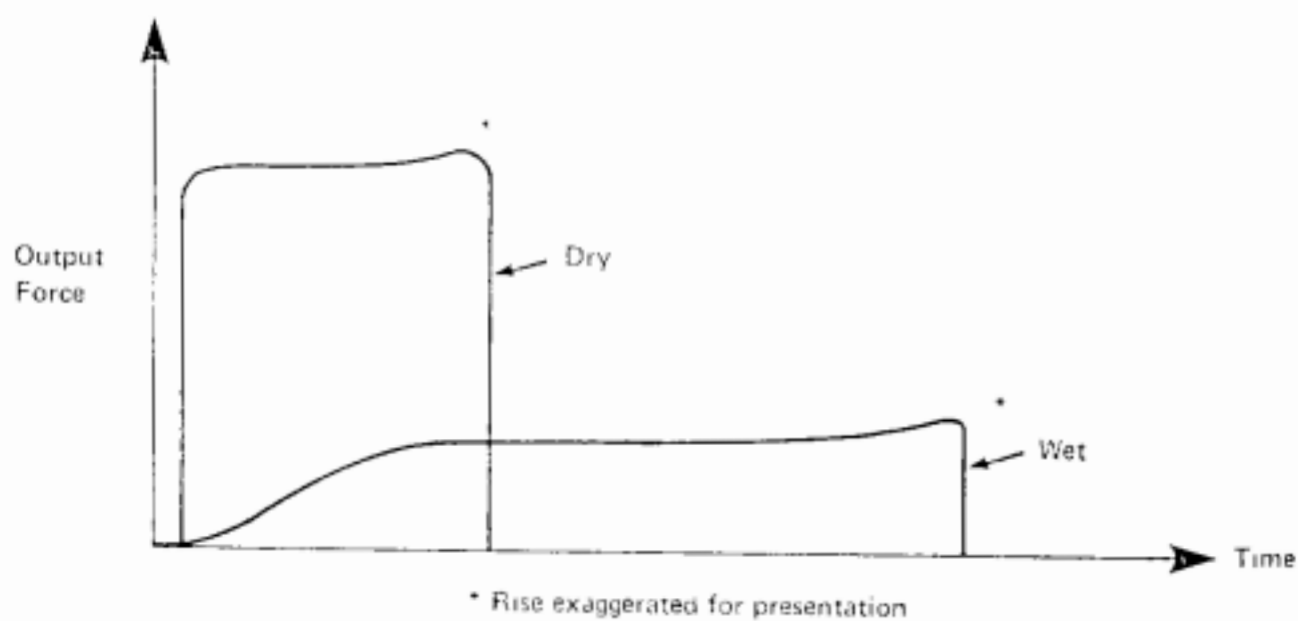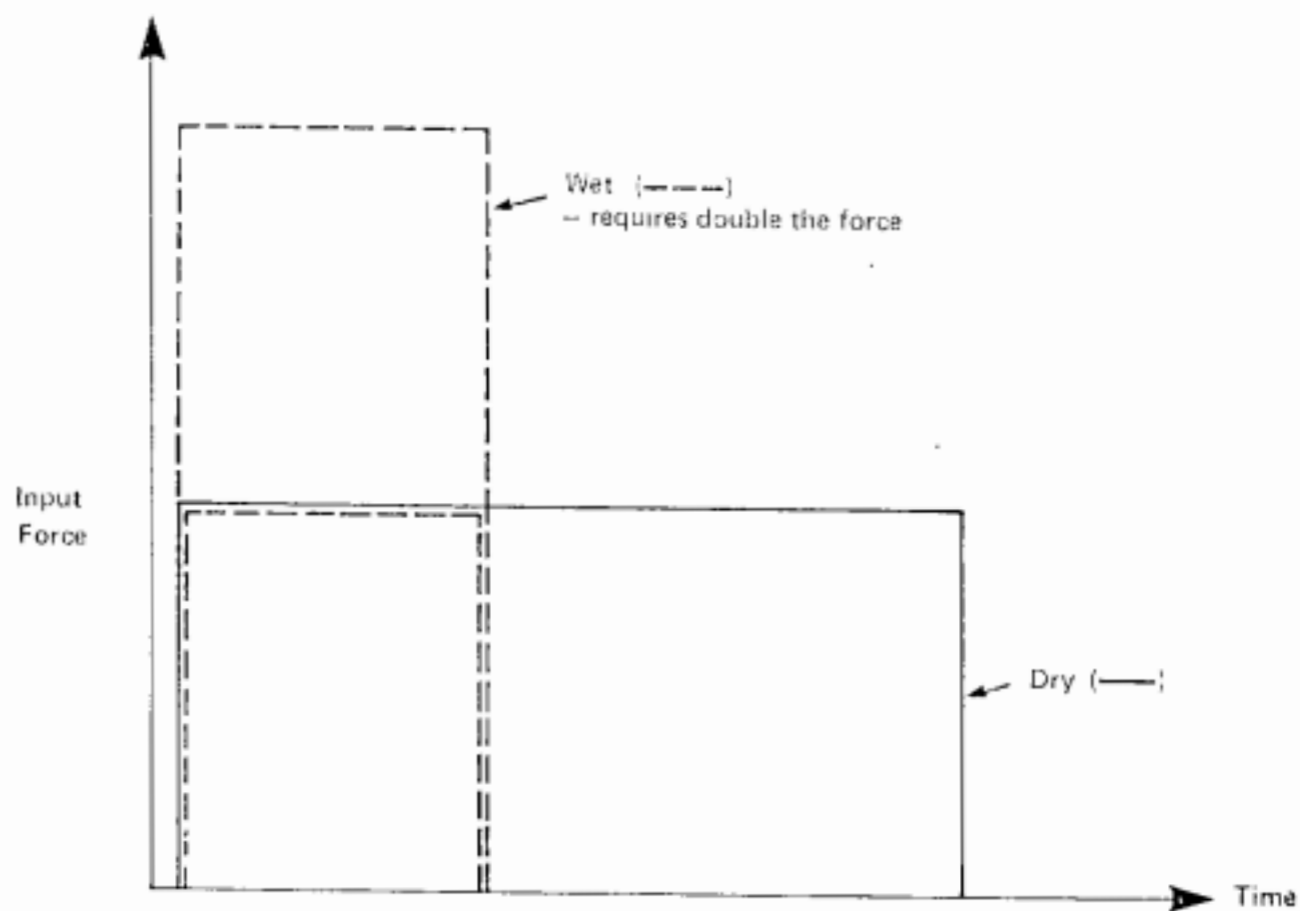
32

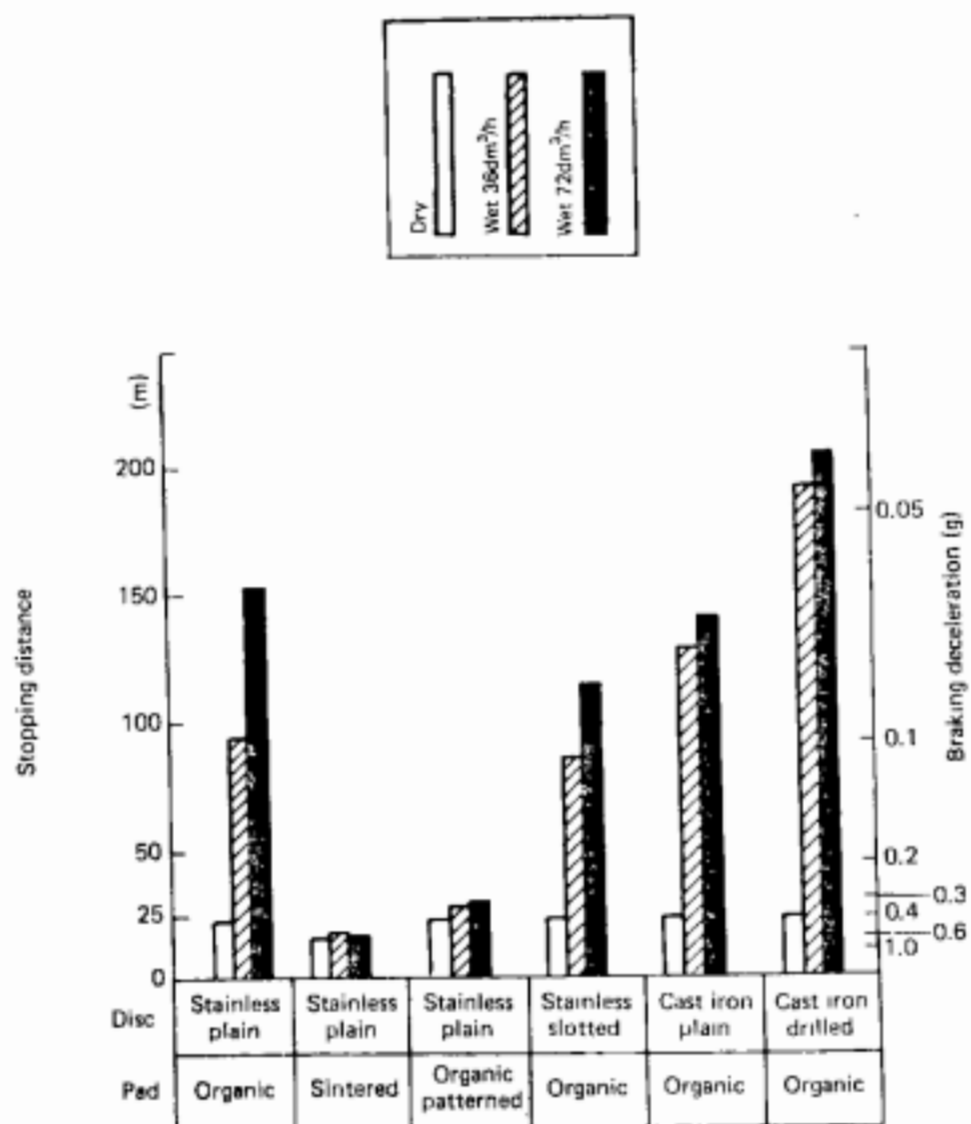Figure 3.1. Response characteristics of disc brakes
(Wigan, 1977).

Figure 3.2. Sintered pad performance (Transport Road
Research Laboratory, 1978 a).

service. Moreover this procedure favours disc brakes, as after submerging the brake, the test requires that the motorcycle be accelerated at the maximum rate to the specified test speed. During this interval the water on the disc is flung off, and testing experience has shown the disc performance to be virtually unaffected (VIPAC, 1979). With road conditions in wet weather, the disc is continuously saturated with rain, spray from the tyres and spray from the mudguards. It is under these conditions that disc brake performance rapidly deteriorates.

3.2.3   Linked Braking Systems

Irving (1978) is of the opinion that many modern motorcycles are overbraked and points out that there has been a trend towards very large brakes, the control of which requires only finger tip pressure.   In an emergency situation, an inexperienced rider is likely to grab the brake lever with all his power thus causing the front wheel to lock and the machine to lose stability. Furthermore Irving shows that to obtain the minimum stopping distance both front and rear brakes must be used together.   It is interesting to note that Irving mentions a brake system employed on a Rudge-Whitworth motorcycle in the late 1920s called 'proportionate braking'. Both the front and rear brakes were applied via a single pedal control. A control lever was also supplied for the front brake. A similar system has recently been reintroduced by the Italian motorcycle manufacturer 'Moto Guzzi' (Manicardi, 1979). This system was designed in conjunction with the brake manufacturer 'Brembo'. Motorcycles fitted with it have two front discs and one rear disc. The left side front disc and the rear disc are hydraulically linked together and are operated by a foot lever. The other front disc is operated by a handlebar lever. Figure 3.4 shows a publicity pamphlet (Moto Guzzi, 1979) which displays expected performance using the integral braking system. However this represents a subjective evaluation, and is not the result of appropriate testing.
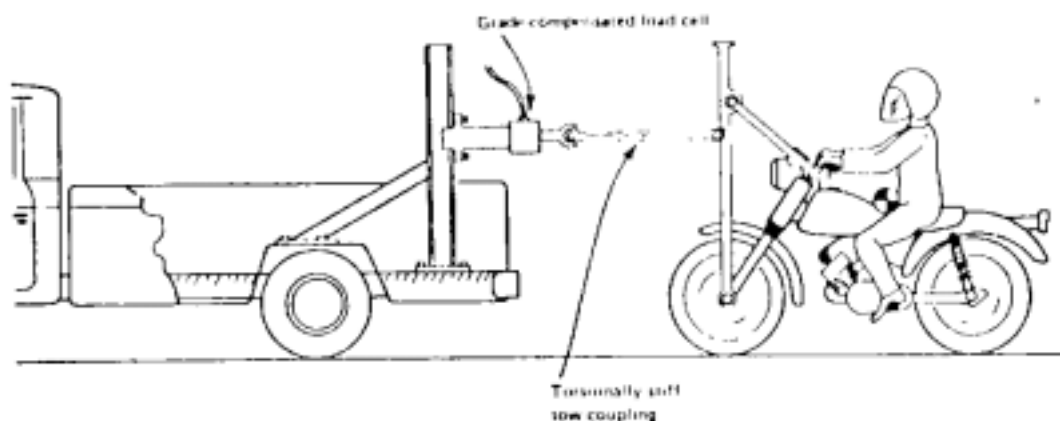
Figure 3.3. Tow-test apparatus (Ervin, MacAdam and
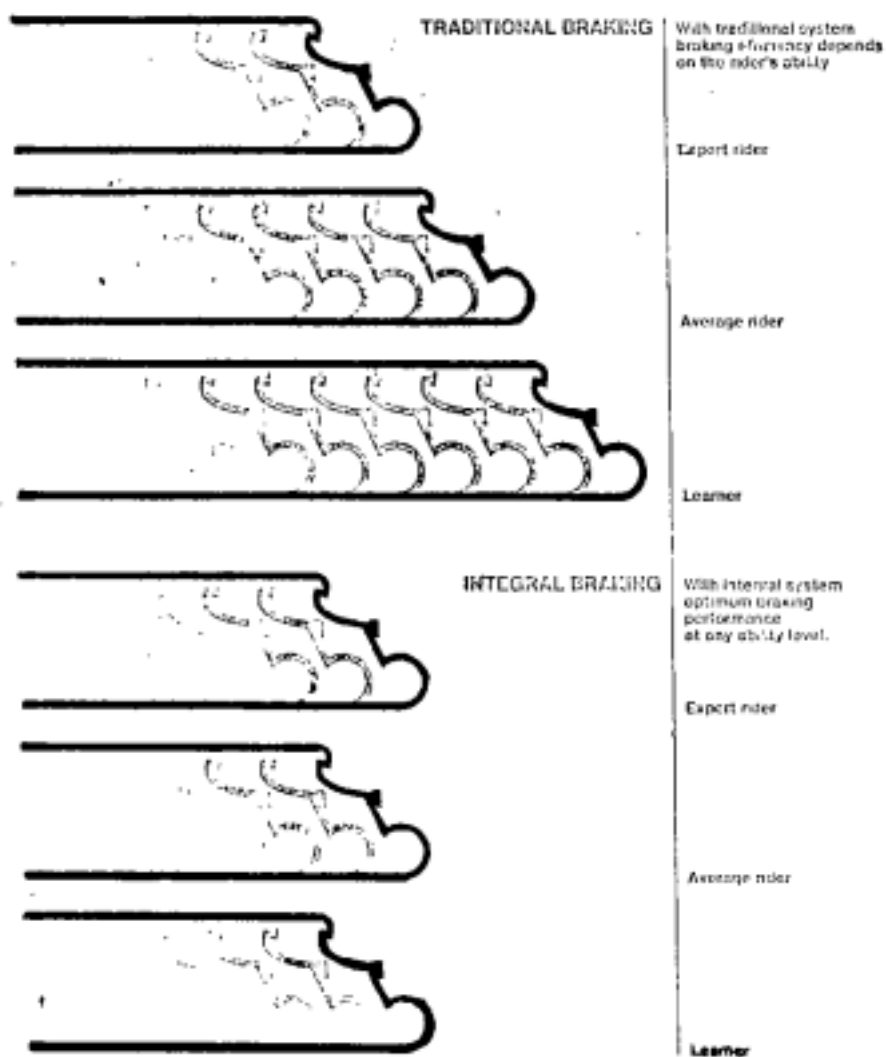Watanabe, 1977).

Figure 3.4. Traditional braking compared to integral
braking (Moto Guzzi, 1979).

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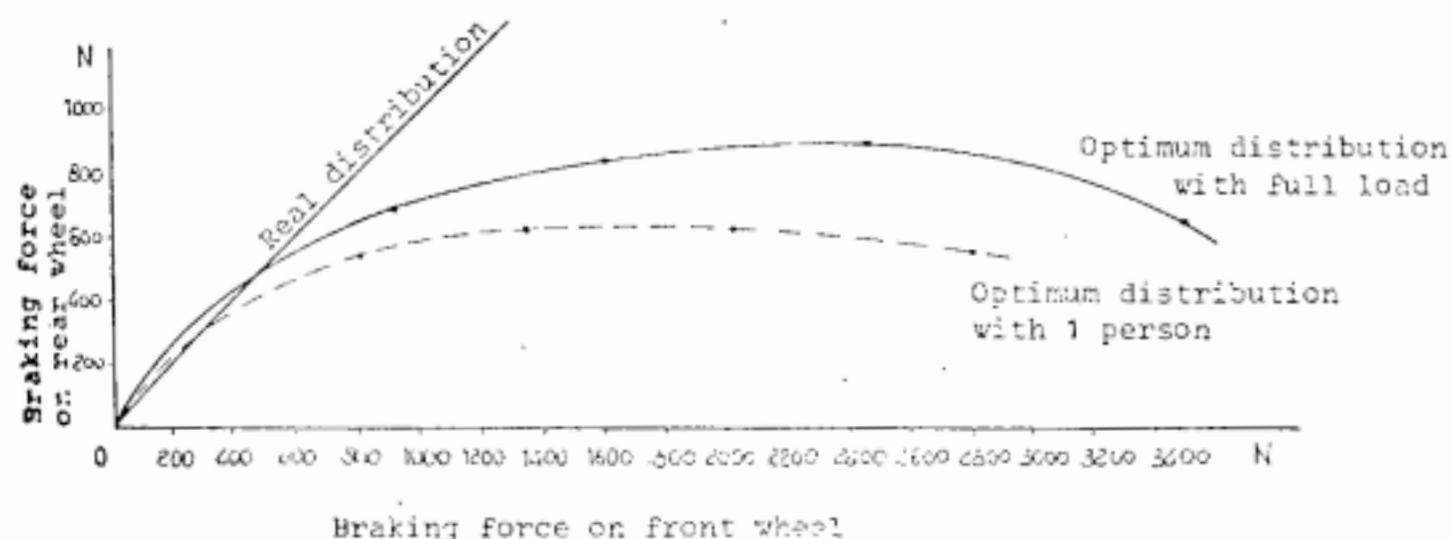## Distribution of braking force with braking system 1

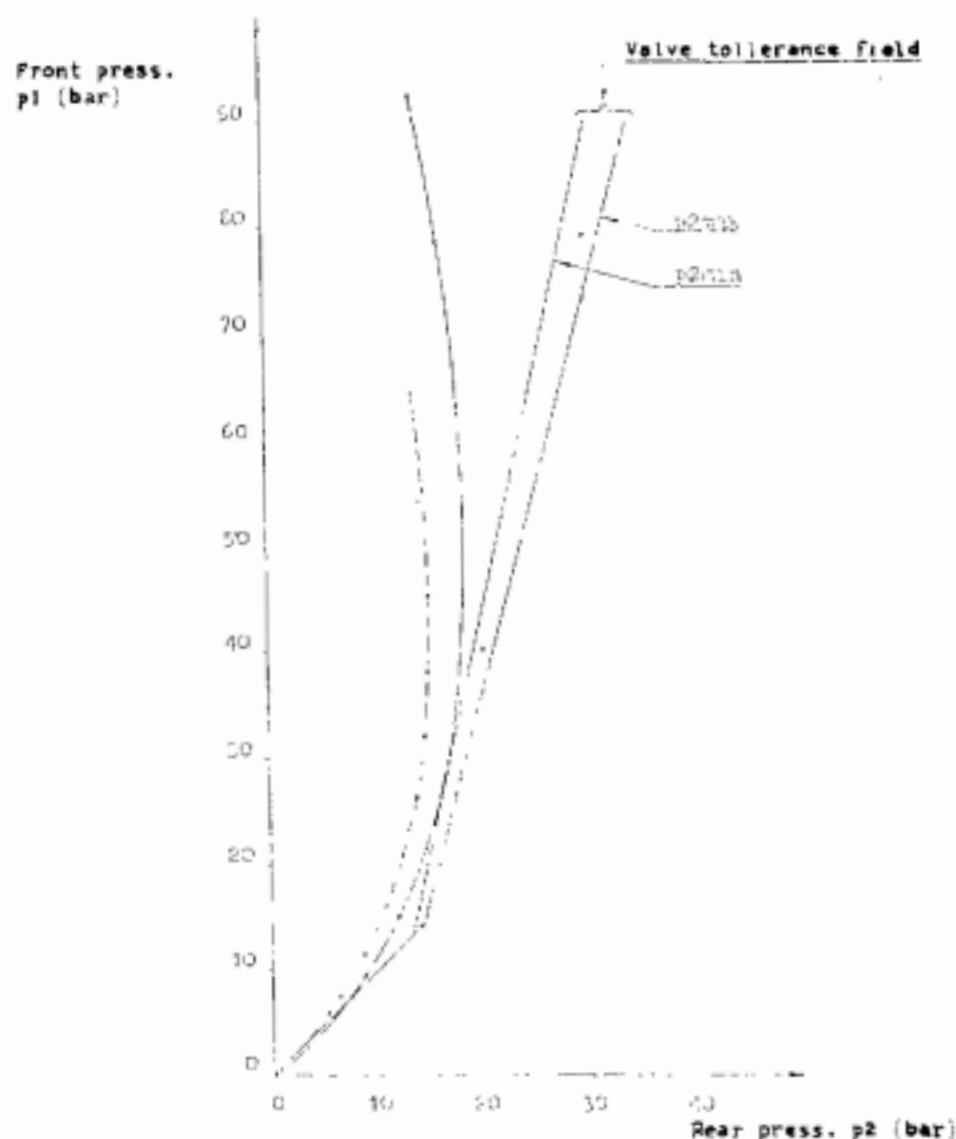Figure 3.5. Brake force distribution of simple linked brake system (Manicardi, 1979).

Figure 3.6. Pressure distribution of fixed shear rate pressure regulator valve (Manicardi, 1979)

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Distribution of the braking force in an
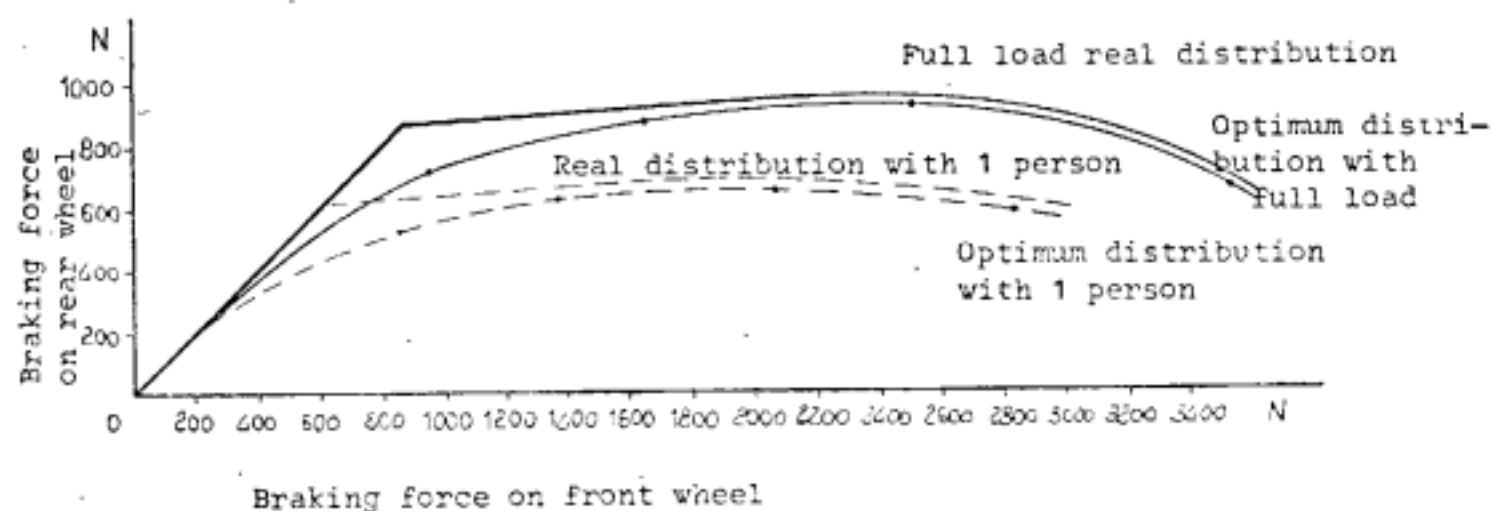integral system with variable load regulator

Figure 3.7 Brake force distribution with variable
proportion linked braking system (Manicardi, 1979).

Ervin, MacAdam and Watanabe (1977) conducted a study to evaluate FMVSS 122, and as a part of this work motorcycle manufacturers were requested to give their views on the evolution of brake technology. Moto Guzzi's contribution consisted of engineering calculations in support of their integral brake system. Two errors were made in the computations which to a certain extent compensated for each other (Ervin et al. 1977). The Moto Guzzi integral braking system has been modified twice since it originally appeared in 1973. The system which Ervin et al. analyzed was the first version, in which proportioning of hydraulic pressure was fixed at 1:1 to front and rear disc. The differing brake torque requirements were accomplished via wheel radius, disc radius and pad friction coefficient variations. The braking force distribution is shown in Figure 3.5. This system suffered from wheel locking problems. Moto Guzzi have modified the simple system and included a fixed shear rate valve, the behaviour of which is illustrated in Figure 3.6. Manicardi (1979) published a paper on this system in which the errors made in the submission to Ervin et al. were corrected. Manicardi includes information about, and the brake force distribution for, an integral system with a variable load regulator. The distribution characteristics are shown in Figure 3.7. This system would appear to have ideal characteristics. Moto Guzzi motorcycles sold in Australia do not have this variable load regulator fitted to them. At the time of writing, no further information was available on this system.

The House of Representatives Standing Committee on Road Safety (1978) recommended in paragraph 68:

> 68. Operation of front and rear brakes together by applying the correct proportion of braking effort to each wheel is a skilled operation of particular concern even to experienced riders. Skidding is a particularly hazardous situation to be avoided on a motorcycle as directional control of the vehicle is

lost and a spill is extremely likely. Many
experienced riders are consequently frightened to
use their front brake and are thereby more than
doubling their braking distance in an emergency by
using only the rear wheel brake. The Committee
therefore recommends that:

* a requirement for licensing be a demonstration of
   the effective use of all brakes fitted to the motor-
   cycle particularly the front brakes; and

* the Commonwealth Department of Transport develop
   advisory performance specifications for this test.

The report recommends in paragraph 70:

* experiments be undertaken to assess the physical
   performance of, and the ability of riders to make
   better practical use of, coupled braking systems as
   exemplified by Moto Guzzi with a view to encouraging
   wide use of this type of system if shown to demon-
   strate an added margin of safety.

3.2.4   Antilock Braking Systems

Watson and Lander (1974) established that motorcycles are more
accident prone than other motor vehicles while the road is wet,
and that skidding is a significant factor in these accidents.
This work prompted TRRL to investigate antilock braking for
motorcycles. Watson, Lander and Miles (1976) said that in 1974 a
total of some 7000 motorcycle accidents involving personal injury
in the United Kingdom involved skidding on both dry and wet
roads. They adapted an experimental antilock brake system
originally designed for cars by Mullard Ltd. for motorcycle use.
Their research showed that, on a range of surfaces with friction
coefficients down to 0.3, motorcycles between 90-225 kg can be

stopped using front wheel braking only without wheel locking, provided they are fitted with the antilock system, and that the performance on good surfaces is not impaired. Some measure of cornering could also be undertaken at the same time as braking on the most slippery surfaces. The improvement that could be expected by the use of an antilock brake system is indicated in the braking distance diagram, Figure 3.8.

Wilkins (1969) investigated in detail 140 accidents involving motorcycles and found that in about 5% of cases the rider was thrown off as a result of wheel locking due to brake application. It was estimated that a further 50% of accidents studied would possibly not have occurred if the motorcycle brakes had either been more efficient, or had been applied earlier. Wilkins established that 10% of motorcycle accidents might be prevented through fitting antilock brakes.

Antilock brake systems suitable for motorcycles have now been at the prototype development stage for about 10 years. There are three fundamental types of antilock brake systems:

   (i)   slip ratio control - whereby the wheel velocity
          and vehicle velocity are monitored to allow a pre-
          determined amount of slip between the two.

   (ii)   wheel deceleration control - the system measures
          the wheel deceleration and compares it to a preset
          maximum allowable level.

   (iii) jerk control - when the rate of change of
          deceleration approaches zero, the braking force is
          a maximum.

The Mullard system investigated by TRRL measured wheel deceleration, and Miennert (1974) applied a similar system to a heavy motorcycle. He reported the system to be an extremely
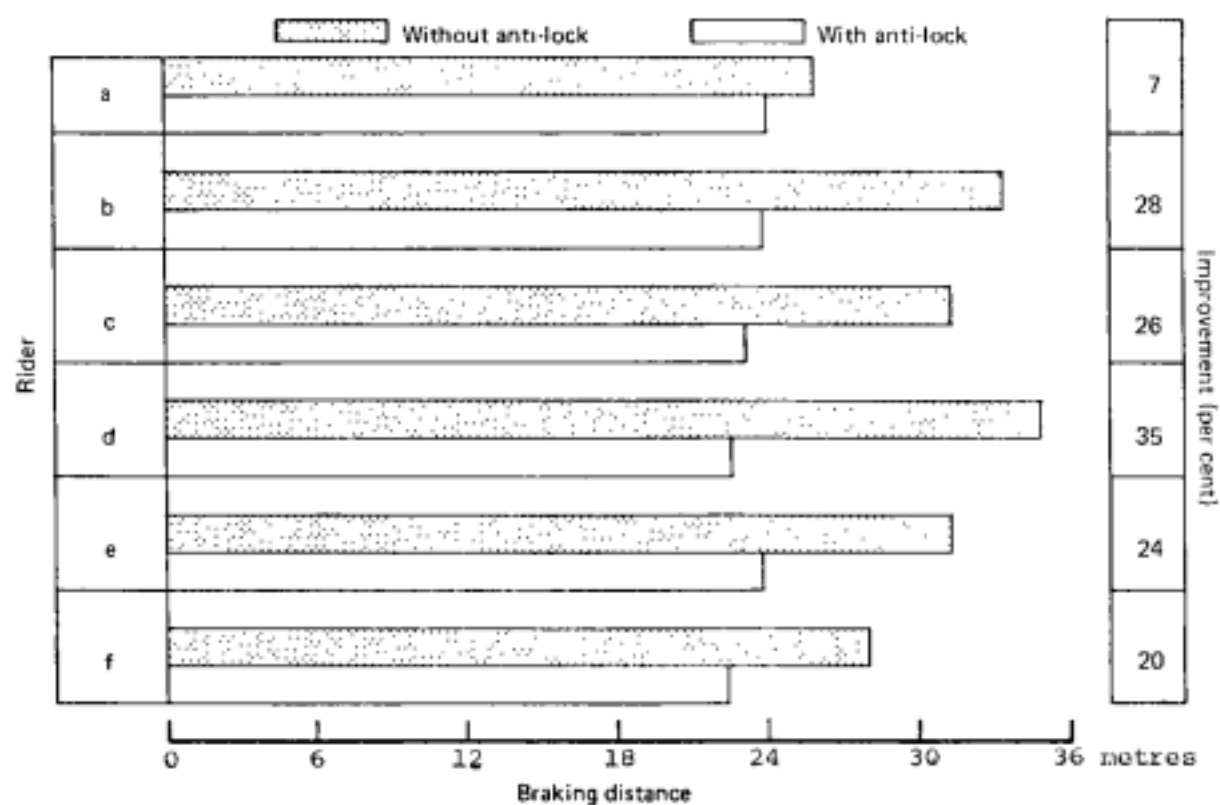
Figure 3.8 Antilock brake performance (Transport Road Research Laboratory, 1978,b).

desirable motorcycle component. However this contention was apparently not supported by exhaustive experimental testing. The only results presented in his report were a comparison between the antilock system and the braking performance of a locked wheel.

Manion and Tenny (1975) presented results of a feasibility analysis using jerk to control the brake lock-unlock sequence, and cited advantages as:

     (i)   yields consistent indication of the maximum friction coefficient, which is a function of wheel slip ratio. Peak friction coefficient occurs when the rate of change of deceleration (jerk) is zero

     (ii)   does not compromise system performance for varying road conditions

     (iii)   control system is simpler

     (iv)   levels of jerk are high; axis crossing is easy to discriminate

However to implement the proposed system, a suitable sensor to measure jerk still had to be developed.

Aoki (1975) investigated a deceleration-sensing antiskid braking system fitted to a Honda CB 350. His test results show that the antilock system significantly improved stopping distance compared to a locked wheel. However the stopping distances are similar to the no-antiskid device, no-locked wheel condition. This system was apparently in early development stages in 1975.

Weir, Zellner and Teper (1978) conducted experimental work to evaluate the Mullard antilock system as fitted to a Norton 850 motorcycle by TRRL. A series of straight line and cornering/ braking tests were undertaken using this system and a

conventional system. Two different road surfaces were used, being dry brushed concrete, and a wet sealed black top surface. The performance of the antilock system was generally superior. On the dry brushed concrete, it gave results nearly the same as those achieved by an expert rider with a motorcycle fitted with a conventional system. An 'open-loop' testing procedure was also used. Pressure limiters were installed in the brake lines, which could be pre-set to give theoretical maximum performance. On the low-coefficient wet surfaces, performance with the antilock system was significantly better than that which could be achieved by either an expert rider or suitably tuned open-loop procedures.

Figure 3.9 shows the results from these experiments. The major advantage of the antilock system is seen to be on low skid number surfaces. Motorcycles are seldom ridden when these conditions exist (Hurt et al., 1981). However they are very dangerous when encountered.

3.2.5 Brake System Modulability

Motorcycle brakes are a dynamic system which have response characteristics characterized by a rider input force-deceleration hysteresis loop (Zellner, 1980). These properties vary from machine to machine. The force/displacement or 'stiffness' properties of the brake system measured at the control lever define its 'feel' properties. Zellner (1980) observed:

> 'Feel properties are the primary means by which the
> rider senses and controls the activity by his limbs
> on the manipulators ... So, manipulator feel
> properties which interface with the limb are of
> interest'.

It is the combination of feel properties and dynamic response characteristics of a brake system that will influence a riders'
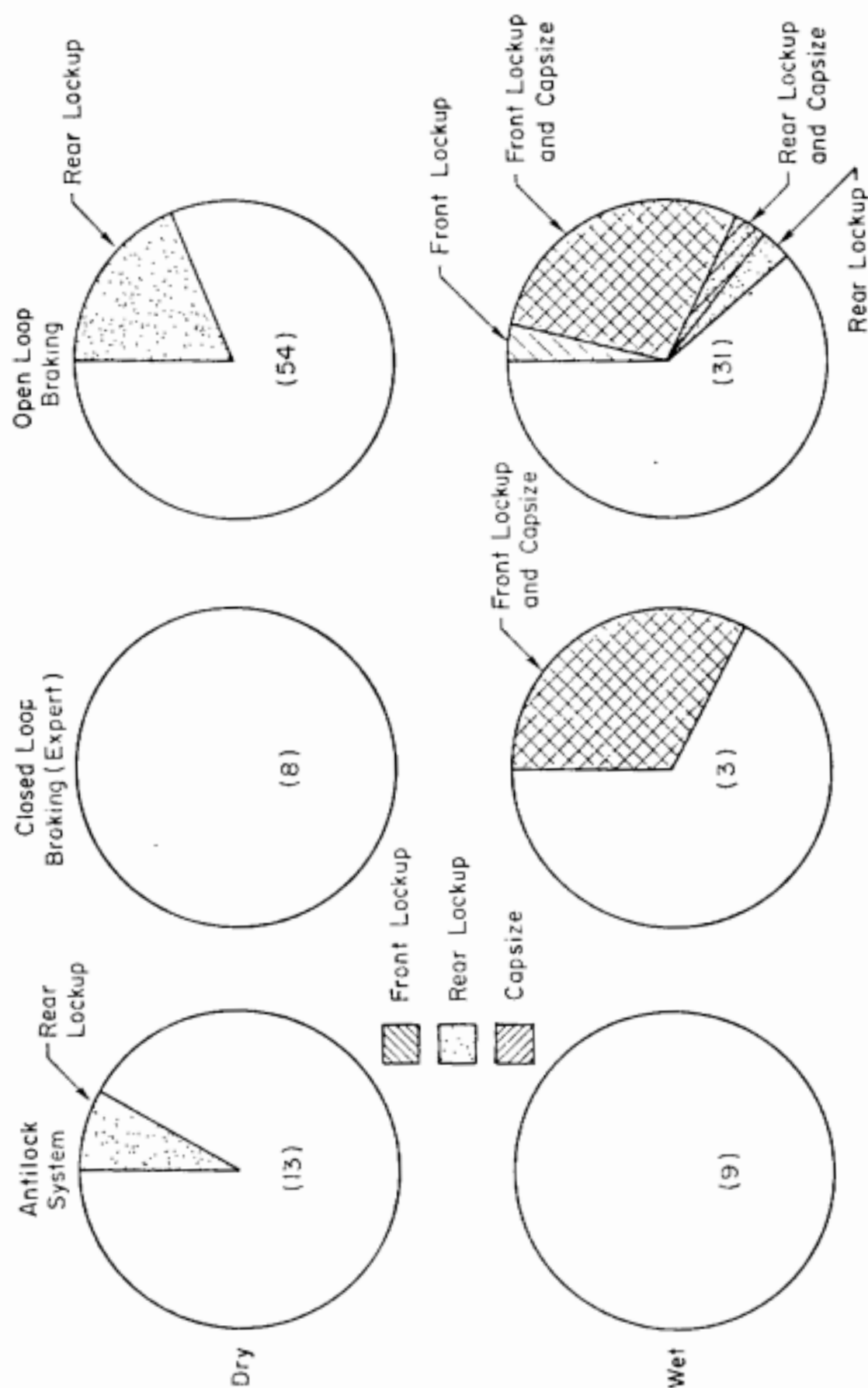
Figure 3.9   Wheel lockup and capsize in braking
manoeuvres (Weir Zellner & Teper, 1978).

impression or rating of it, and moreover his ability to modulate and control deceleration.

Motorcycle magazine road tests publish stopping distance figures as a measure of brake system performance. The variations of brake dynamic response characteristics and rider ratings are not reflected in stopping distance tests. The following information extracted from 23 road tests from the Australian magazine TWO WHEELS supports this contention:

Initial speed 100 km/h, mean stopping distance = 36.4 m, std. dev. = 2.75 m

Initial speed 60 km/h, mean stopping distance = 12.14 m, std. dev. = 1.43 m

The standard deviation for both speeds is small when experimental errors and variations due to different tyres and road surfaces are considered. The data suggest that the motorcycles tested all had similar maximum deceleration capabilities despite the wide variations in subjective ratings of the brakes given for these machines (cf., Figure 4.20). The average deceleration represented by the mean stopping distance is 1.08 g for 100 km/h and 1.17 g for 60 km/h initial speed.

The derivation of simple equations to predict motorcycle deceleration is given in Appendix A. It is shown that when both front and rear brakes are used together up to the limit of the available tyre-road friction coefficient (μ), the maximum attainable deceleration is μg m/s^2. When only one of the brakes is used, up to the friction limit, the maximum deceleration is reduced considerably. A plot of percentage of available deceleration versus μ (using the data for six motorcycles from Rice, Davis and Kunkell, 1976) is shown in Figure 3.10. With surfaces of characteristically high μ (dry bitumen μ = 1), using the rear brake alone will realize approximately 45% of an average motorcycles' braking potential. The situation is generally
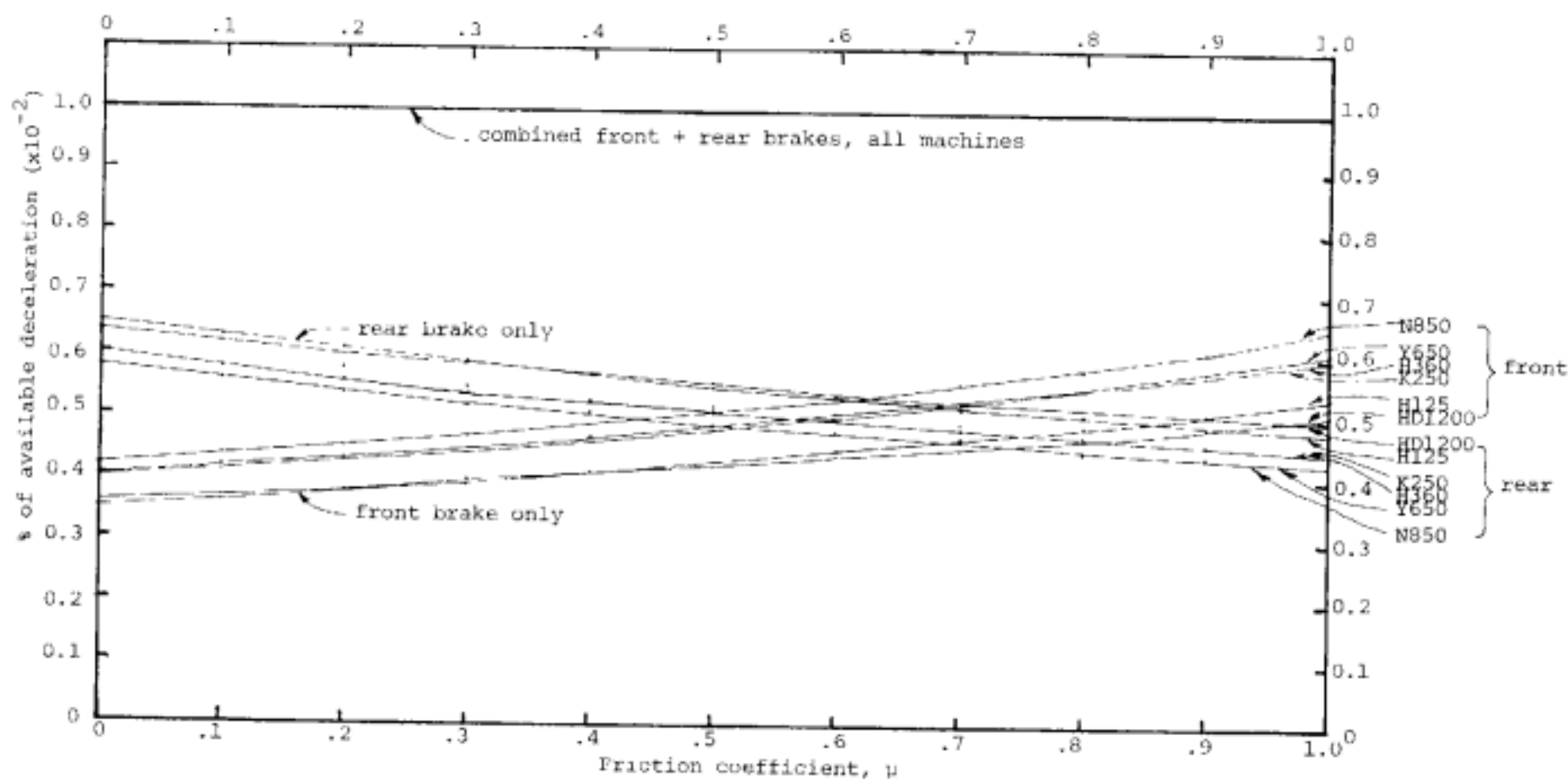
Figure 3.10   Percentage of available deceleration versus friction coefficient (see Appendix E)

slightly worse with large machines and better with small machines, due to differing geometrical configurations. On the basis of a brake reaction time of one second (Johansson and Rumar, 1971), then typically only one second will be available for effective deceleration, given that on average a motorcyclist has two seconds for collision avoidance (Hurt, 1979). Further, if the initial speed is assumed to be the urban/suburban limit of 60 km/h (where most accidents occur), then using both brakes will result in an impact speed of 25 km/h; if using the rear brake only, 44 km/h. The kinetic energy of the vehicle at 44 km/h is about three times that at 25 km/h, which would result in a collision of much greater severity than if both brakes had been used. It was concluded in Chapter 2 that many motorcyclists do not use both brakes in an accident situation. The reasons for this are not known; it could be due to a fear of locking the front wheel, or due to a poor understanding of the correct procedure for efficient stopping.

As yet the dynamic behaviour and transfer characteristics of the motorcycle brake control system have not been identified. Furthermore, the ergonomic capabilities of the human operator for this control task are not yet known. There is a pressing need to obtain such data so that brake systems may be designed to maximize the rider's ability to control deceleration and minimize wheel locking. These requirements apply equally to the linked braking system. The linked system has an inherent advantage in that it forces the motorcyclist to use both front and rear brakes simultaneously, with obvious advantage in an accident situation.

3.3   CONCLUSIONS

(i)   Motorcycle disc brake performance in wet weather is not
        satisfactory due to slow response, the high input force
        levels required and variable and unpredictable responses.
        Sintered metal pads appear to offer considerably improved

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performance. However only one manufacturer as yet incorp-
orates them as original equipment, and they are not
available as retro-fit items in Australia.

(ii) Australian Design Rule 33 'Motorcycle and Moped Braking
Systems' has areas which are inadequate in relation to
measuring brake performance in wet conditions. This
design rule is in need of modification so as to more
accurately model actual wet weather braking conditions.

(iii) Linked braking systems appear to offer considerably better
braking performances for unskilled operators. The
variable proportioning system (mooted by Moto Guzzi but
not currently available in Australia) appears to have
ideal characteristics. However, there is a lack of
published information on experimental or in-service
performance of linked brake systems.

(iv) Antilock brakes offer excellent braking performance in
wet, slippery conditions, virtually independent of the
operator's skill level. They are still in developmental
stages, and are not yet commercially available.

(v) Motorcycle brake 'feel' and response behaviour has not yet
been properly quantified. Furthermore, the ergonomic
capabilities of the rider are still to be understood.
Work in this area is urgently required in order that brake
systems may be designed which will give most riders the
confidence and ability to realize the full deceleration
capacity of their machines.

4. STABILITY AND HANDLING CHARACTERISTICS

4.1 MATHEMATICAL MODELS OF RIDER/MOTORCYCLE SYSTEM

The modelling of the rider/motorcycle system has developed from the analysis of bicycle-alone dynamics. This knowledge was extended and applied to motorcycle-alone motions and, more recently the rider has been included as an active part of the dynamic system.

4.1.1 Motorcycle-alone Dynamics

The first significant work on the stability of the motion of a bicycle was that of Whipple (1899). He discussed the general motion of a bicycle with circular wheels making point contact with the ground, and he was able to identify dynamic instabilities with the model. Pearsall (1922) and Kondo, Nagaoka, and Yoshimura (1963) made further contributions to the analysis of the stability of bicycle.

Wilson-Jones (1951) made the earliest significant contribution towards understanding the dynamics of a motorcycle. He described roll and steering wobble instabilities, and recognized that the generation of cornering forces resulted primarily from camber rather than slip angle for single-track vehicles. As well, he proposed that it was necessary to supply a negative steer torque to initiate a turn, a view which was very controversial at the time but is now well recognized.

The first complete and concise mathematical model of lateral motorcycle dynamics is due to Sharp (1971). His model consisted of a vehicle with two rigid frames joined at the steering axis, with the wheels being represented by rigid discs each making point contact with the road. Tyre forces were represented as linear functions of wheel camber and slip angle. The rider was considered to be a rigid mass lumped with the rear frame. The
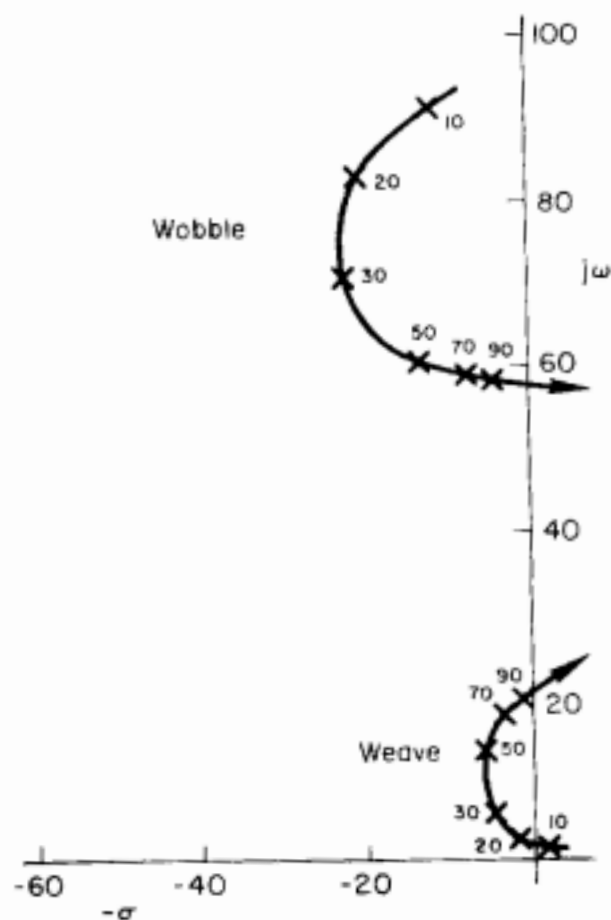
Figure 4.1   Effect of forward speed on weave and wobble modes
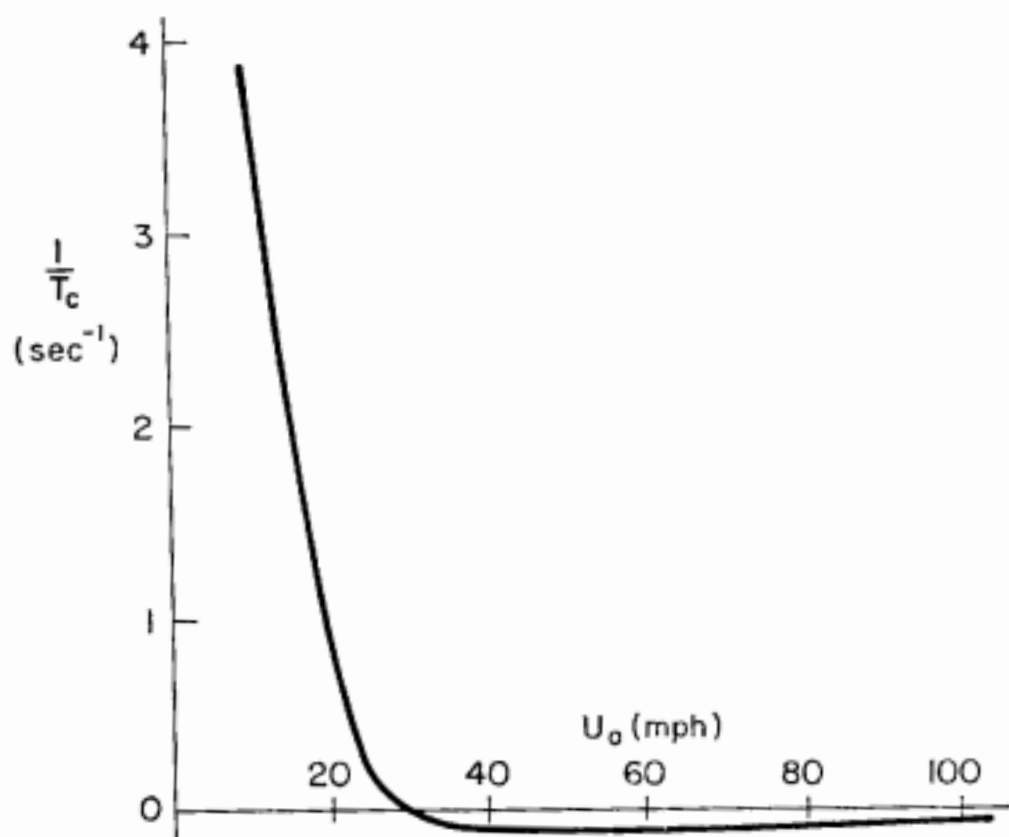
(Weir, Zellner and Teper, 1978)

Figure 4.2. Roll mode divergence (Weir Zellner and Teper, 1978).

machine moved at constant speed with degrees of freedom in side-
slip, yaw and roll. The equations of motion were linearized and
the eigenvalue problem was solved with a digital computer. The
model showed that the motorcycle had three physically significant
modes. These modes are illustrated in Figure 4.1 by way of root
locii, with motorcycle forward speed as a parameter (Weir,
Zellner and Teper, 1978). The mode for which the steer angle is
the most significant component of the eigenvector is called the
wobble mode, and becomes unstable at high speeds for this
particular machine. The weave mode consists of a coupled roll,
steer and yaw oscillation and with this machine is seen to be
unstable at both very low and very high speed. The frequencies
of these modes are such as to put them beyond the control
abilities of a rider, should they become unstable. The capsize
mode is aperiodic. At low speeds it is usually stable. At
higher speeds it becomes mildly divergent, thus requiring
continuous control by the rider. The inverse time constant for
this mode is illustrated in Figure 4.2.

Sharp (1974) extended his original model to investigate frame
flexibility effects. He also investigated the effect of
acceleration and deceleration on stability (Sharp, 1976 a) and
the influence of the suspension system on weave mode oscillations
(Sharp, 1976 b). Sharp and Alstead (1980) looked at the
influence of structural flexibilities on straight running
stability. There have been investigations of motorcycle dynamics
by many other workers (Eaton, 1973; Ellis and Hayhoe, 1973; Segel
and Wilson, 1977; Verma, 1978; Watanabe and Segel, 1980; Koenen
and Pacejka, 1980). It can be concluded that motorcycle-alone
dynamics are now reasonably well understood. However the main
uncertainty with this work would appear to rest with accurate
representation of tyre dynamics and the lack of empirical data to
describe motorcycle tyres. Furthermore there have been only a
few attempts to experimentally validate the motorcycle dynamic
models. These areas still require further attention.

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The following practically significant implications for motor-
cycle frame design can be drawn from the motorcycle-alone dynamic
studies:

* wobble mode is most sensitive to steering damping
  (Sharp, 1971)

* a high speed motorcycle frame should have the rear frame
  centre of gravity low and as far forward as possible,
  and the front frame centre of gravity as far back as
  possible (Sharp, 1971)

* an increase of torsional flexibility in the rear forks
  reduces the weave damping at medium and high speeds
  (Sharp, 1974)

* acceleration has a significant stabilising influence on
  the capsize mode (Sharp, 1976 a)

* the pitch mode natural frequency should be kept away
  from the weave mode frequency to prevent coupling of
  these two modes during cornering manoeuvres (Sharp, 1976
  b)

* for large motorcycles, the torsional stiffness of the
  rear swinging arm suspension member should be of the
  order of at least 1.2 kNm/rad to minimize weave mode
  oscillations (Sharp, 1974)

* for a machine of conventional frame geometry, the
  optimum rear frame torsional stiffness will lie in the
  region of 80 kNm/rad, provided the front forks are stiff
  laterally (greater than 200 kN/m) This value should
  make wobble mode damping constant throughout the speed
  range of the motorcycle and of an adequate level (Sharp
  and Alstead, 1980)

4.1.2 Modelling of Rider/Motorcycle System

The first published analysis of rider/motorcycle dynamics was
that of Weir (1972). At all but very low speeds, Sharp (1971)
predicted that the roll mode will be unstable so that without
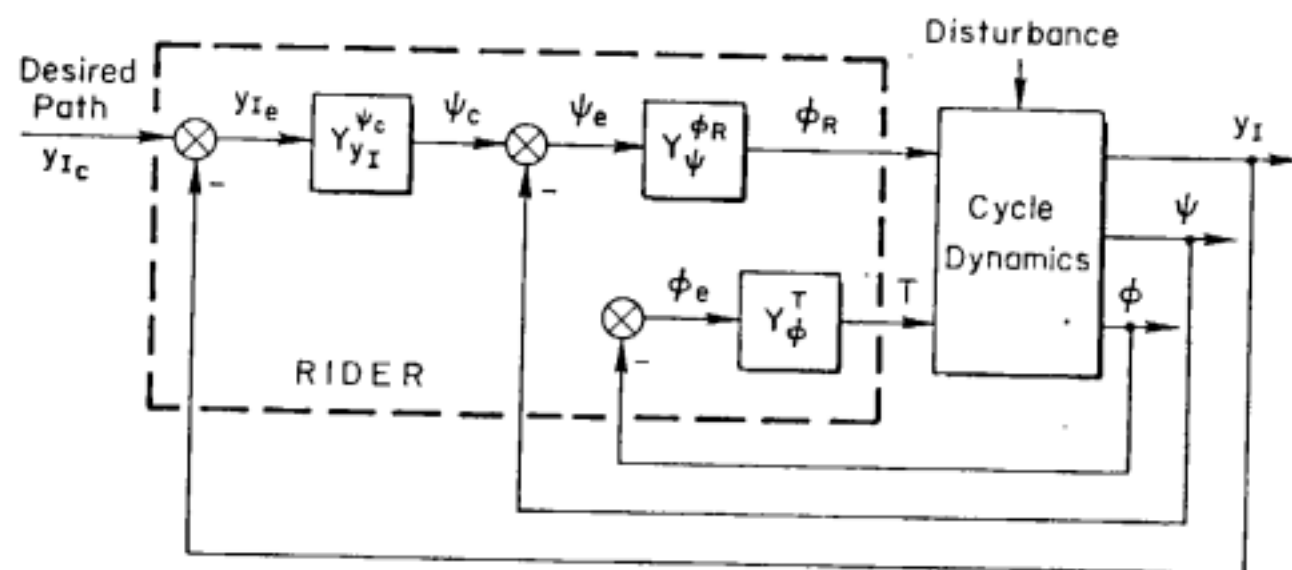rider control inputs, the motorcycle will fall over. Weir argued

Figure 4.3 Motorcycle rider control model (Weir, Zellner and Teper, 1978).

that the inclusion of the rider and his actions in the analysis of motorcycle dynamics is essential to a complete understanding of the system behaviour. The rider's control action, aimed at stabilising the roll behaviour, modifies the vehicle's effective stability and disturbance response characteristics.

Weir stated that for the manual vehicular guidance and control task, the requirements are to follow the desired path and reduce any path errors to zero in a stable, rapid and well-damped manner. He found that rider upper-body lean angle could be used for 'outer' loop control of heading and lateral position. To control roll angle, the rider's best strategy was to use steer torque. The 'inner' loop of roll angle is therefore central to the handling qualities of the vehicle. Figure 4.3 shows the rider control model developed by Weir.

Rice, Davis and Kunkel (1976) used a non-linear model of the motorcycle/rider system with eight degrees of freedom to simulate motion in straight line running, constant speed turns and lane-change manoeuvres. An instrumented motorcycle was used to obtain experimental data. The simulated rider required more time and distance to execute a lane change than did the actual rider. They concluded that further modifications to the simulation were necessary to include suspension effects, braking and acceleration capability, rider model improvements, and a more sophisticated tyre model.

Rice and Kunkel (1976) performed supplementary investigations to those of Rice et al. (1976) using the lane change manoeuvre, including both simulation and experimental work. They attempted to cover rider influences to a greater depth, and to complete the investigation of several motorcycles in a simulated lane change manoeuvre. A plan view of the path used for lane change is shown in Figure 4.4. Figure 4.5 gives a direct comparison of the simulated performance of the different motorcycles with respect
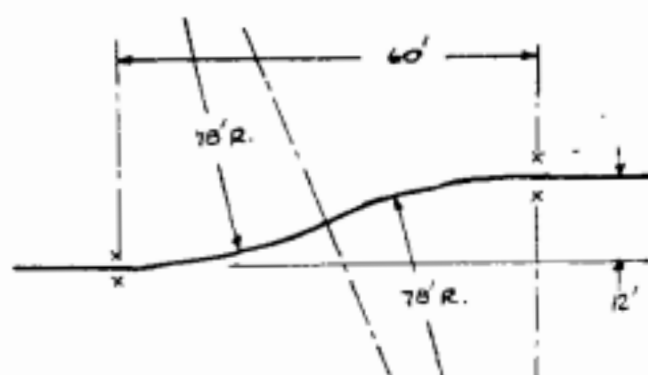
Figure 4.4   Lane change manoeuvre, plan view (Rice and
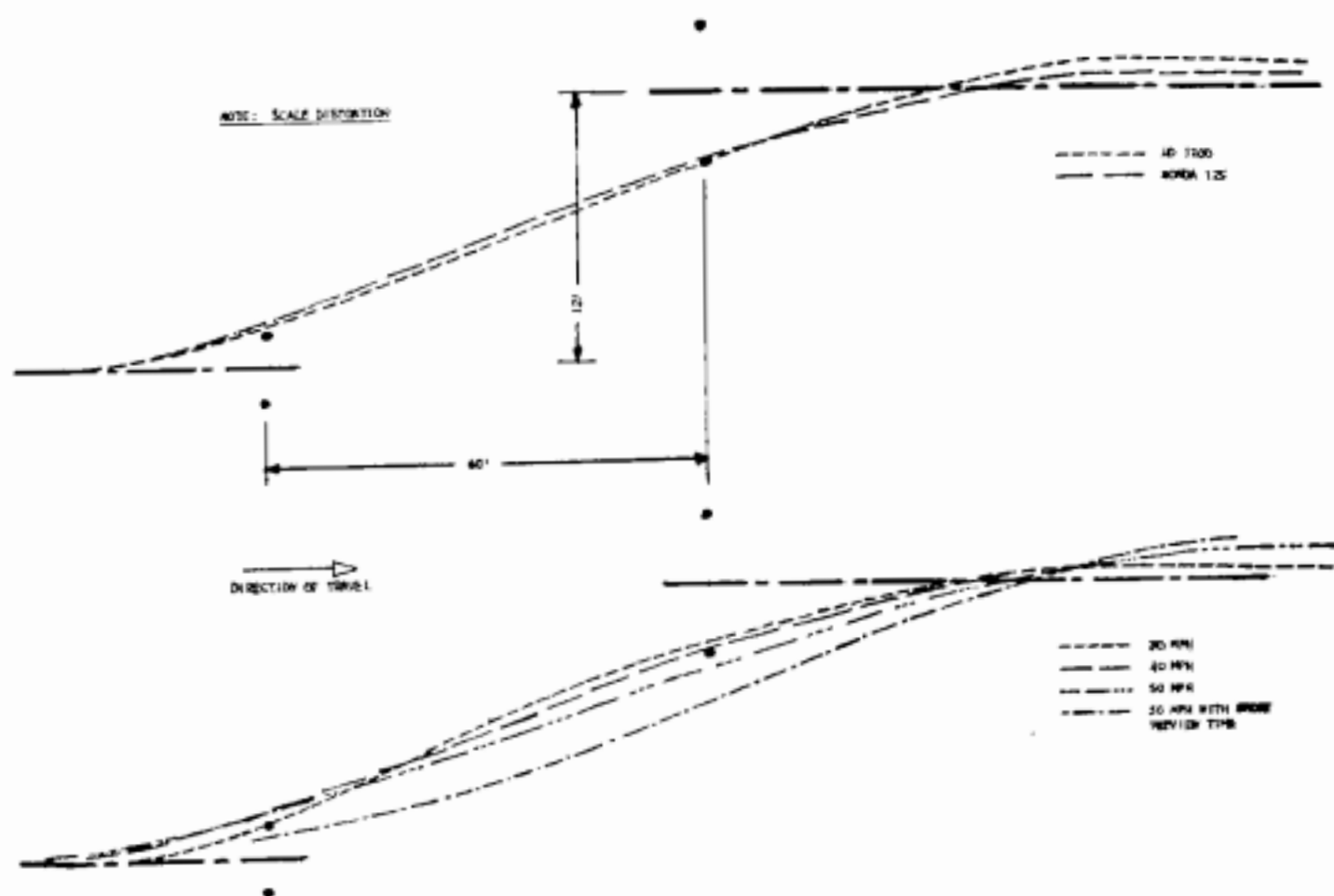   Kunkel, 1976).

Figure 4.5   Path comparisons and speed effects in lane
            change manoeuvre (Rice and Kunkel, 1976).

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to the lane change path. It can be seen that the paths are very similar (results for smallest and largest motorcycles only have been shown).

Weir, Zellner and Teper (1978) used a non-linear motorcycle/ rider model in analyzing handling response and performance. The simulation program provides for all-axis, large amplitude motions of the vehicle. These include lateral directional motions, longitudinal motions, coupled lateral and longitudinal motions, and coupled lateral and longitudinal response. Structural compliances in the front fork assembly and the rear swing arm are represented. Provision is also made for open and closed-loop rider control actions, involving handlebar steer torque and rider upper body lean. The model is intended for analysis of wobble, cornering weave, roll over, incipient spins, braking in a turn, and evasive manoeuvres.

Figure 4.6 shows results of a simulated entry into a steady turn for a Honda CB 360 motorcycle and rider. Figure 4.7 shows the rider model used in the simulation. The command input was a ramp of roll angle θ_c as shown in Figure 4.6. The steady state roll angle of 0.05 rad corresponds to a lateral acceleration of only 0.05 g. This is a mild manoeuvre which does not test the non-linear features of the simulation.

At present the non-linear simulation has very limited application, as all but one of the gains in the rider model are unquantified. Extensive analysis is required to put values to these gains, and then further experimental work would be required to validate them. However, a validated rider/cycle simulation would be an extremely valuable tool for safe and economical testing of the influence of a variety of machine and rider skill variables on handling performance.
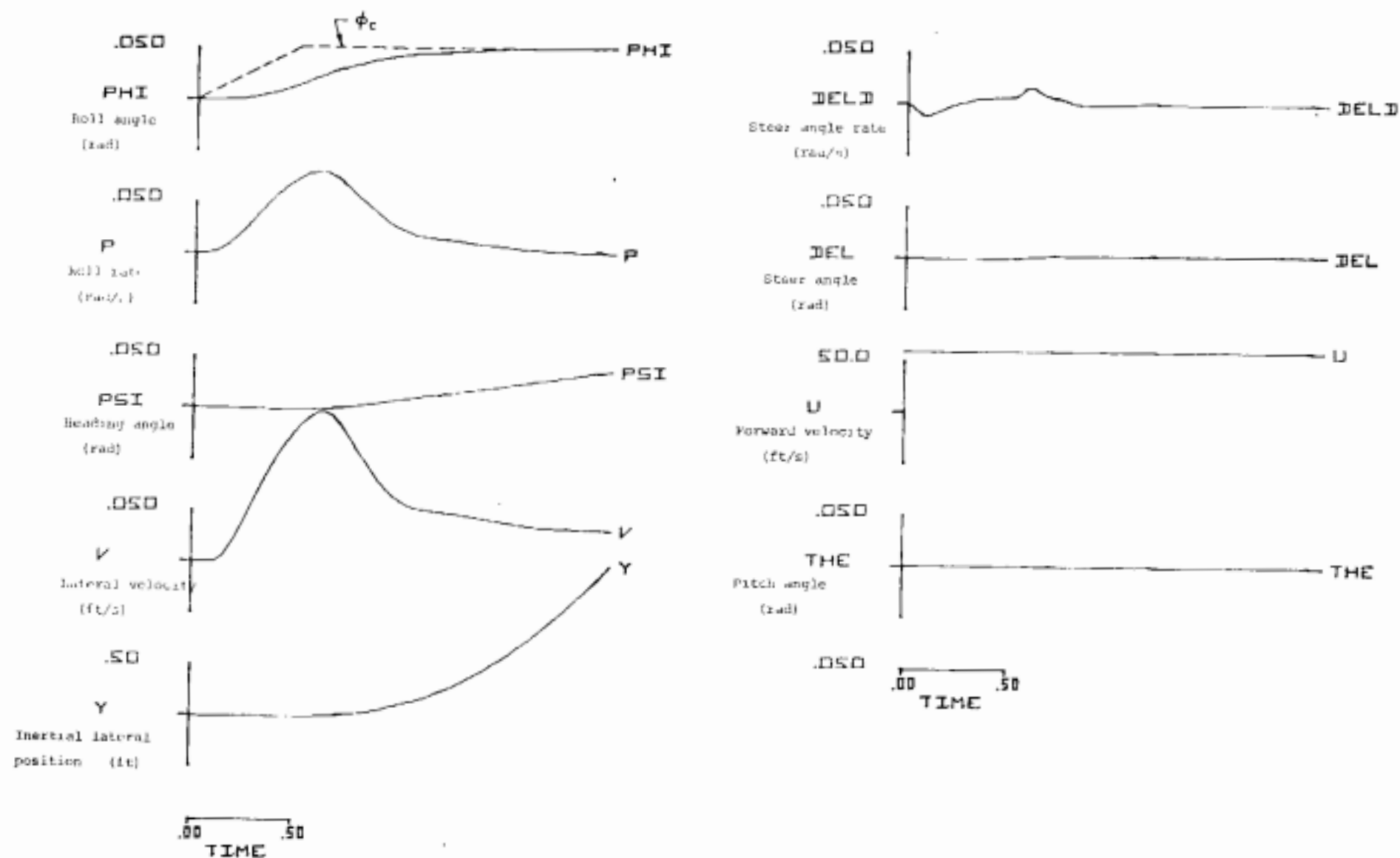
Figure 4.6   Non-linear rider/motorcycle simulation during transition to steady turn (Weir, Zellner and Teper, 1978).
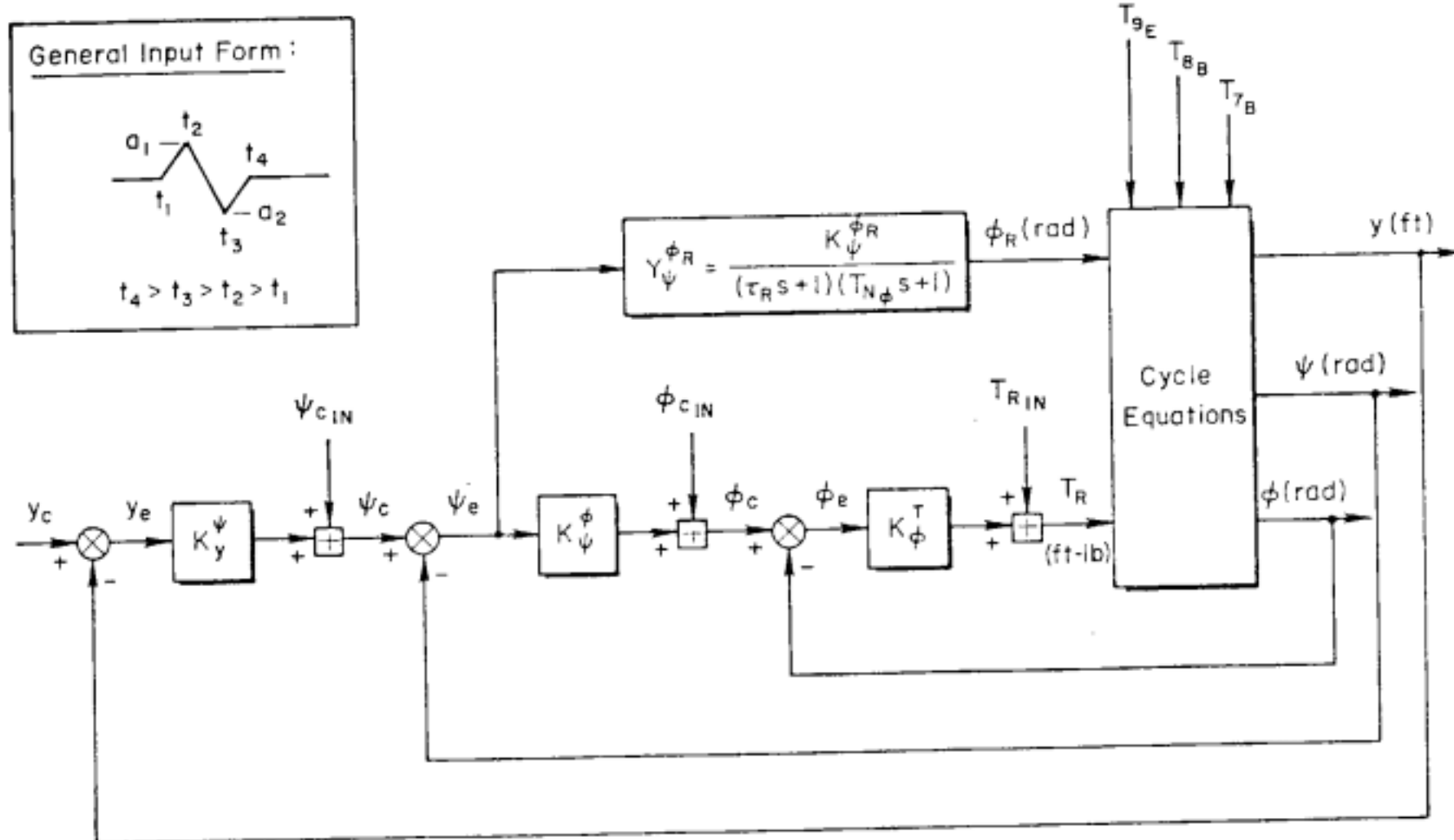
General Input Form:

t_2
a_1
t_4
t_1
$-a_2$
t_3

$t_4 > t_3 > t_2 > t_1$

$Y_\psi^{\phi_R} = \dfrac{K_\psi^{\phi_R}}{(\tau_R s + 1)(T_{N_\phi} s + 1)}$

$\phi_R (rad)$

T_{9_E} T_{8_B} T_{7_B}

Cycle Equations

$y (ft)$

$\psi (rad)$

$\phi (rad)$

$\psi_{c_{IN}}$

$\phi_{c_{IN}}$

$T_{R_{IN}}$

y_c y_e K_y^ψ ψ_c ψ_e K_ψ^ϕ ϕ_c ϕ_e K_ϕ^T T_R (ft-lb)

Figure 4.7 Rider model used in non-linear simulation (Weir Zellner and Teper, 1976).

4.2   EXPERIMENTAL INVESTIGATIONS OF RIDER/MOTORCYCLE PERFORMANCE

Wilson-Jones (1951) conducted an experimental investigation into
rider behaviour in a turn, and identified rider strategies. The
rider first steered away from the intended turn in order to set
up the appropriate roll angle. This understanding was
controversial at that time, as evidenced by the published
discussion at the conclusion of the paper. Hurt (1973)
experimentally established that Wilson-Jones' understanding of
the cornering manoeuvre was correct. Hurt pointed out that very
few riders were aware of how they made a turn, and that in an
accident situation the rider may well turn his machine into the
obstacle as he tries to steer away from it.

Watanabe and Yoshida (1973) investigated evasive handling
performance and braking of motorcycles. The test method employed
involved the rider heading towards an obstacle. At a measured
distance from the obstacle a signal lamp indicated to the rider
to veer left or right, as shown in Figure 4.8. The tests were
conducted at 50 km/h, 80 km/h and 100 km/h using three different
motorcycles (small, medium and large) with riders of varying
experience (and skill). Figure 4.9 shows the required evasion
distance versus speed for all riders and all motorcycles. The
distance required for avoidance increases roughly in proportion
to the increase in velocity. Rider skill is a more significant
factor than motorcycle size in determining emergency handling
performance. Low skilled riders required 15-20% greater distance
to avoid the test obstacle than skilled riders.

Watanabe and Yoshida (1973) defined an 'avoidance ability
coefficient' as the quotient of the distance required for evasion
and the test velocity. Avoidance ability coefficient was used to
compare the performance of different riders and motorcycles. On
this basis the 125 ml machine had the lowest performance of the
three motorcycles, while the 350 ml and the 750 ml machines
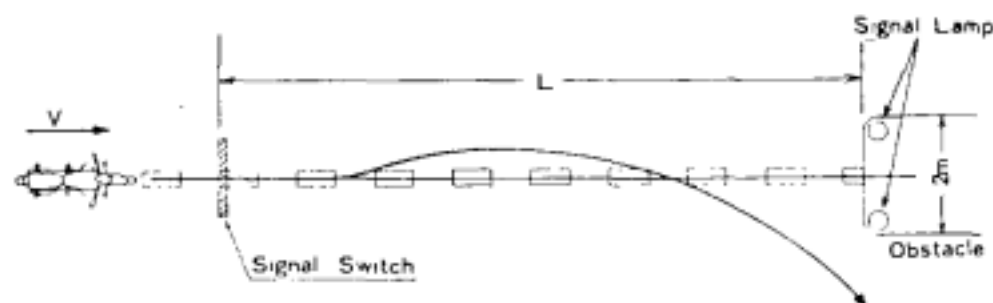behaved similarly. It was therefore concluded that it could not

Figure 4.8   Plan of obstacle avoidance manoeuvre (Watanabe and Yoshida, 1973).
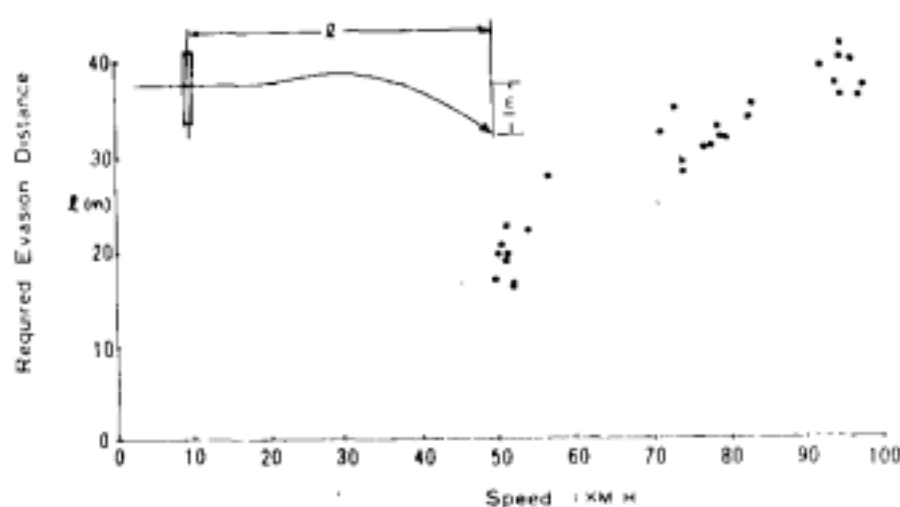

Figure 4.9   Required evasion distance versus speed in the obstacle avoidance manoeuvre (Watanabe and Yoshida, 1973).
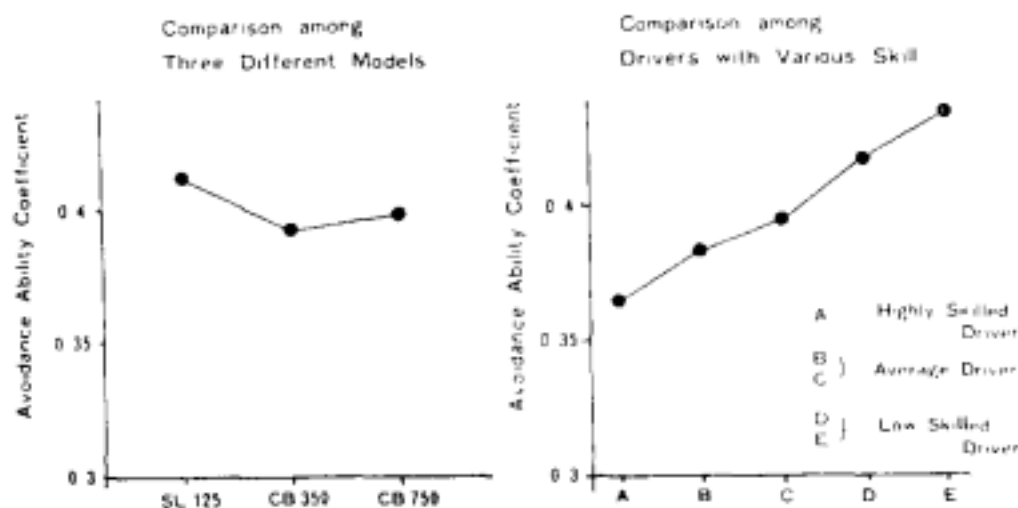

Figure 4.10   Effects of machine and rider skill on avoidance ability coefficient (Watanabe and Yoshida, 1973).
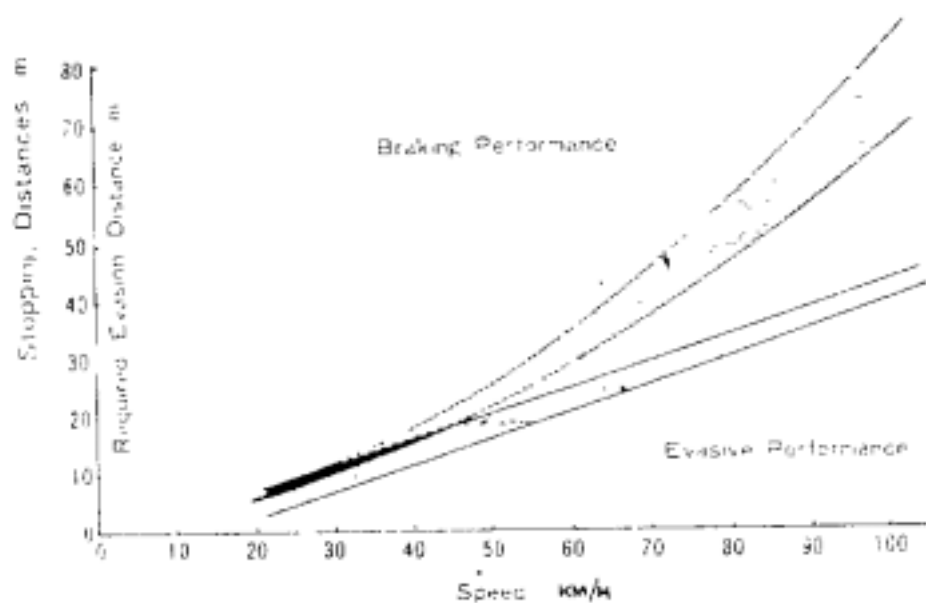
Figure 4.11 Comparison of evasive handling and braking
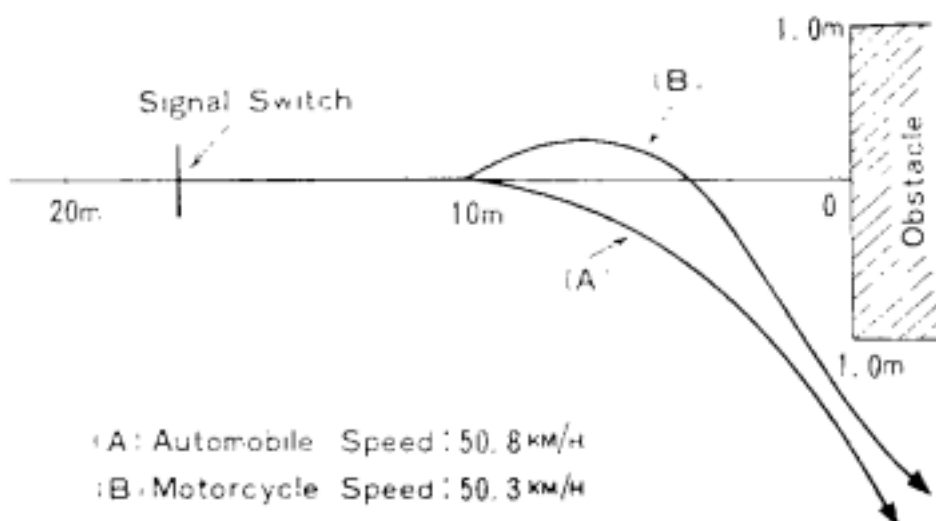manoeuvres

Figure 4.12 Evasive paths of an automobile and a
motorcycle (Watanabe and Yoshida, 1973).

be assumed that a large and heavy motorcycle would be inferior to a small light motorcycle in emergency handling performance. These effects, along with rider skill, are shown in Figure 4.10.

Tests were also conducted to determine straight-line stopping distance when using the brakes. This enabled the comparison of evasive handling and braking shown in Figure 4.11. Braking distance increases in proportion to the square of the velocity. The tests showed that at 30 km/h, braking and avoidance required the same distance. At higher speeds, the braking distance is the longer. It was concluded that, at speeds encountered in normal traffic conditions, evasion may be a better strategy than braking to avoid obstacles.

Motorcycles are generally considered to be more manoeuvreable than automobiles. Figure 4.12 shows the avoidance paths taken by a motorcycle and an automobile. From these tests Watanabe and Yoshida concluded that a motorcycle should not be considered more manoeuvreable than an automobile, because of the relatively long distance required by the motorcycle to establish the roll angle for a turn.

Weir, Zellner and Teper (1978) conducted analytical and experimental studies of the handling responses and performance of five different motorcycles. Five test riders were used in the experiments. They had a wide range of experience, skill and age. The machines used for this work were a Honda 125, a Kawasaki 250, a Honda 360, a Norton 850 and a Harley Davidson 1200. Steady turn single lane change, cornering and braking, and cornering and accelerating tests were performed. Data collected included rider inputs, vehicle motions, and rider subjective evaluation of motorcycle performance.

The steady turn test was used to measure motorcycle control gains under a variety of operating conditions.

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The performance measures evaluated included the ratio of steer torque to cycle roll angle and the ratio of steer torque to yaw velocity (which both relate to the rider providing roll stability and damping); the ratio of yaw velocity to steer angle (with its variation in forward speed providing the 'under/over-steer' characteristic as commonly used with automobiles); and the ratio of steer torque to steer angle (measuring the steering 'feel' properties).

The small Honda 125 showed substantial oversteer, and the large Harley Davidson 1200 exhibited large understeer. The motorcycles with neutral to modest oversteer properties were rated more highly by the test riders. Correlations were also made between rider ratings and total directional damping, defined as:

Total Damping $\approx 2\xi_1\omega_1 + 1/T_c$

where ξ_1 = weave mode damping ratio

           ω_1 = weave mode natural frequency

           T_c = capsize mode time constant

This factor is said to be a measure of the low and mid-frequency damping which is important to rider control, and there-fore does not include the wobble mode and other high frequency effects. It appeared that riders preferred more total damping in the mid-speed range. Vehicles with total damping that decreased too much at high speed were not favoured. This corresponds to the weave mode destabilising at high speed.

Path performance of the motorcycle was also evaluated. The measure used was the root-mean-square (r.m.s.) displacement of the motorcycle from a prescribed circular track, measured with a downward-pointing movie camera attached to the motorcycle. This r.m.s. path deviation showed no variation with speed or with motorcycles for a given level of lateral acceleration, which

illustrates riders' abilities to adapt to changes in vehicle dynamic behaviour. Path performance worsened as lateral acceleration was increased.

There was a lack of simple correlation between path performance and stability factor, total directional damping or capsize mode inverse time constant across motorcycles. Further analytical work and experimental investigation was recommended.

The single lane change test was used to study the maoeuvring performance of the motorcycles and the rider/cycle system because it emphasises the transient response of the vehicle. The path was defined by a painted line on the roadway. In order to establish rider control strategy during a transient manoeuvre, tests were conducted with the rider instructed to complete the lane change without steering torque input, using only lean for control. The vehicle response was slow and less precise than with steer torque, showing the importance of rider steer torque as the major directional control input.

Weir et al. (1978) said that from an analytical viewpoint the weave mode frequency and damping should have an influence on the riders' ability to control the motorcycle in a transient manoeuvre. The higher the weave mode natural frequency, the greater the potential bandwidth of the rider/cycle system. As speed decreases, so does the weave mode natural frequency, although to some extent this is offset by an increase in capsize mode inverse time constant. Weir et al. also showed that heavier motorcycles have a lower weave mode natural frequency suggesting that their performance may be poor at low speed. However, the relationship between mid-frequency vehicle dynamics and the actual motorcycle performance in the lane change tests was not clearly established, and the authors suggest further investigation.

The high-frequency cycle response properties, obtained from computation with a linear simulation of motorcycle dynamics, were related to subjective measures from the lane change experiments. Figure 4.13 shows rider rating versus roll-acceleration/steer-torque gain at high frequencies. A rapid turning manoeuvre is made by rolling the motorcycle via a torque input, and this parameter was expected to be important. However little correlation was found. Figure 4.14 shows rider rating versus yaw-acceleration/steer-torque gain and a definite trend is discernable. The riders preferred a motorcycle which began to yaw initially, rather than the first response being a change of roll angle. It was suggested that better correlation would be obtained if experimental gains were used rather than the calculated gains from the linear simulation, as the latter suffered from uncertainties.

The study by Weir et al. (1978) represents the most comprehensive attempt yet made to determine the most significant motorcycle handling response parameters. The inconclusive results obtained attest to the difficulties in this area and the fact that the study of motorcycle handling is still in its infancy.

Cornering-whilst-braking tests were also conducted by Weir et al. (1978) using the Honda 360 motorcycle. Pressure limiters were used in the brakelines to control braking levels. The results indicated that the maximum deceleration obtainable is reduced when a motorcycle is negotiating a turn. The addition of rear braking caused the motorcycle to go from slightly understeering to more neutral steering, with little variation as speed was reduced. With front wheel braking a similar transition was noted. On heavy application of the front brakes, the motorcycle oversteered to a greater extent as speed decreased. Rider subjective ratings were lower under high levels of deceleration, indicating the increased workload. Cornering and accelerating tests were conducted, and the results differed little from the
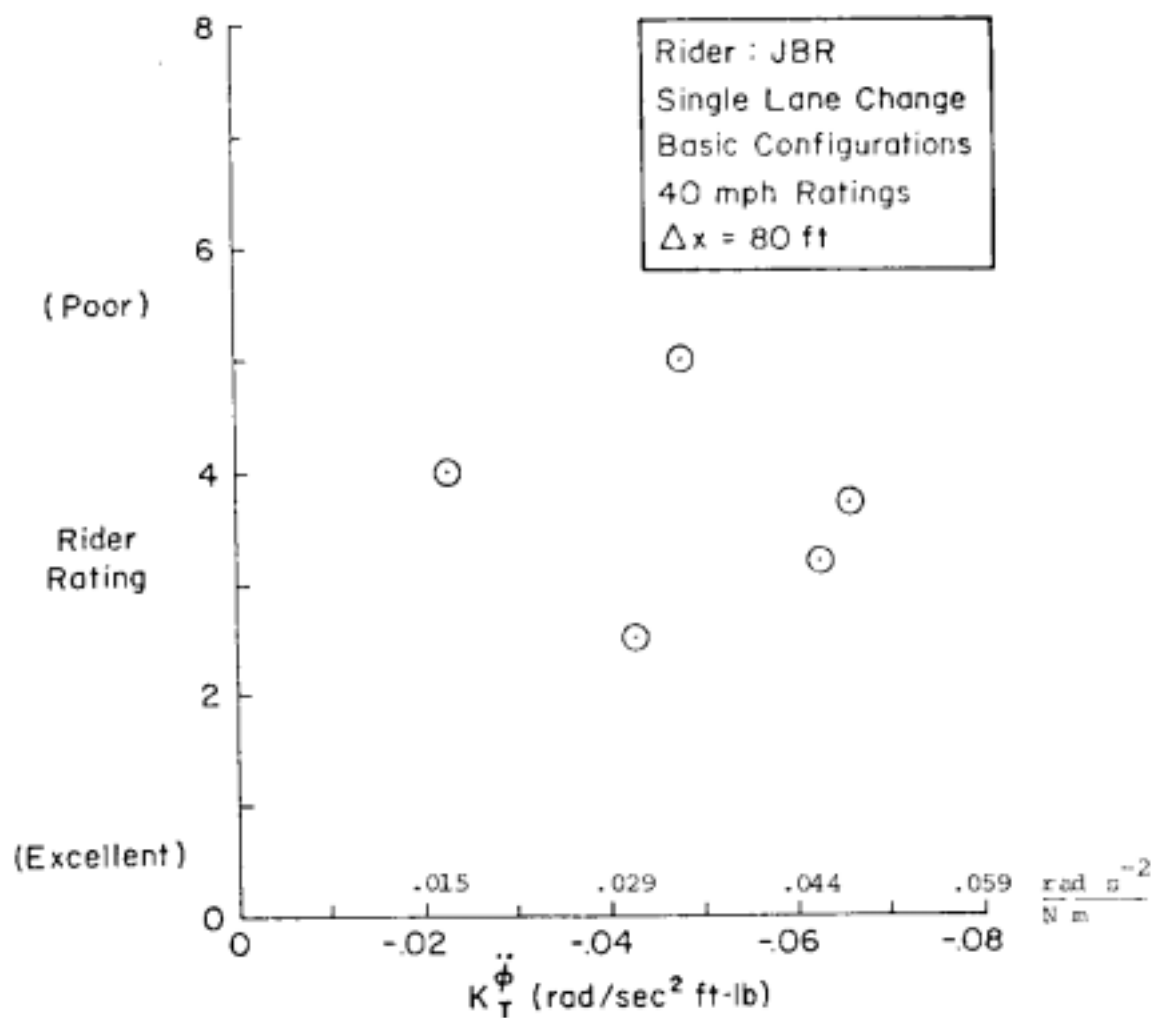
Figure 4.13 Rider ratings versus roll angle per
steer torque sensitivity in the single
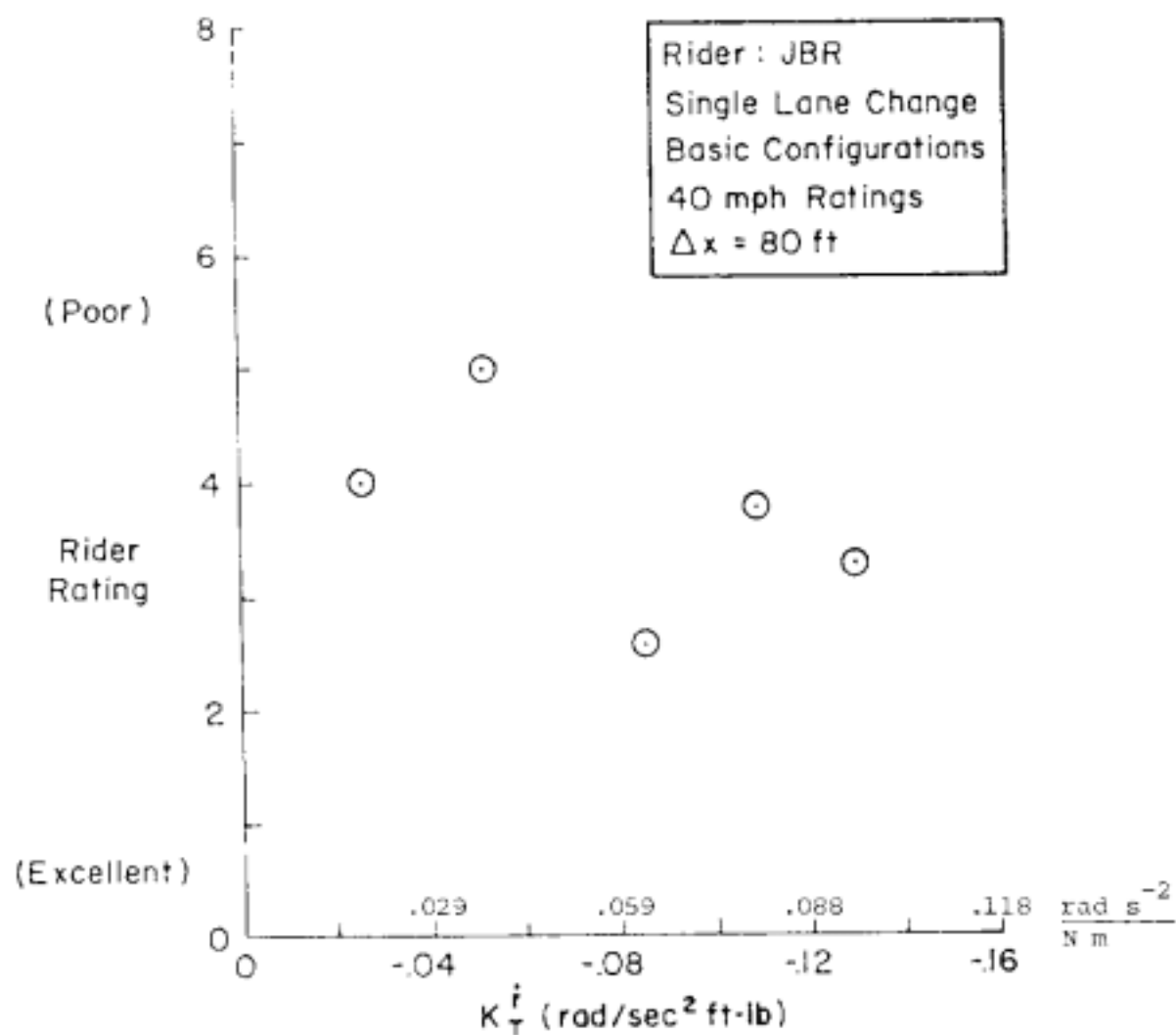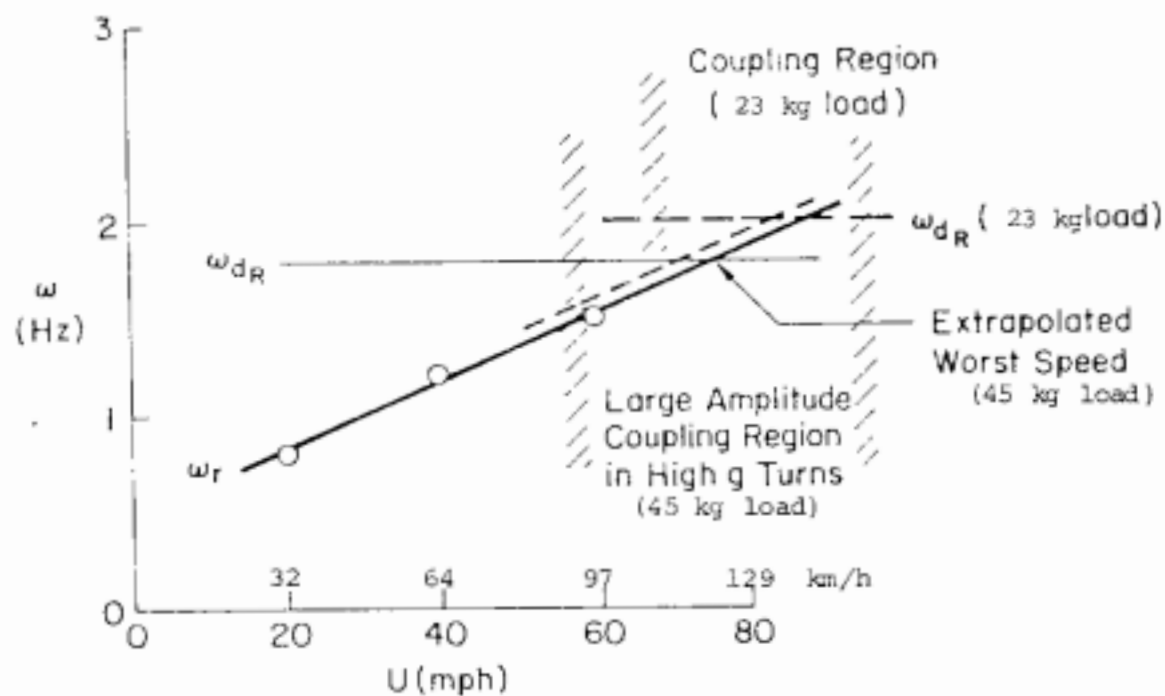lane change manoeuvre (Weir Zellner and
Teper, 1978).

Figure 4.14   Rider ratings versus yaw acceleration per
steer torque sensitivity in the single lane
change manoeuvre (Weir, Zellner and Teper,
1978).

steady turn cases, except at very low speeds where the motorcycle understeered to a greater extent.

Weir and Zellner (1979) published further analysis of the data collected from the experimental program of Weir et al. (1978), concentrating on the transient behaviour of the Honda 125, the Honda 360 and the Harley Davidson 1200. They found that addition of a rear load of 10% gross vehicle weight can lead to weave oscillations in near-limit steady turns. Good damping properties of the rear shock absorbers are important to limit this behaviour. Addition of weight in front of the steering head on the front fork assembly decreased the weave damping and natural frequency. A fork-mounted fairing lowered the wobble mode frequency, and aerodynamic disturbances from the fairing excited wobble oscillations at high speed. Furthermore it was found that a cornering weave occurred in high lateral acceleration steady turns due to coupling of the pitch mode and the weave mode. The coupling occurs as a result of the large roll angles in such turns (Sharp, 1976 b). They were able to predict a critical speed region for this phenomenon, where the weave and pitch mode natural frequencies coincide. This range was from 95 km/h to maximum speed for the Honda 360 (with 45 kg rear load) as shown in Figure 4.15. Also the limiting roll angle was found to be due to ground clearance rather than tyre side force limits.

Chenchanna and Koch (1979) analysed the stability and handling characteristics of motorcycles using both analytical and experimental techniques. A linear model of the rider/motorcycle system was developed. It incorporated a rider model which had rider lean resulting from motorcycle roll angle, rider steer torque resulting from yaw rate and rider steer torque resulting from steer angle. Experimental values for these feedback gains were obtained using a laboratory motorcycle simulator. The equations were solved using a digital computer to obtain eigen-

Figure 4.15 Lateral-longitudinal coupling in high
            acceleration turns (Weir and Zellner, 1979).

ω_{dR} = observed rear suspension frequency with 45 kg rear load

ω_r = apparent weave frequency in yaw velocity trace with 45 kg
      rear load

values. The capsize mode, weave mode and wobble mode were identified.

A motorcycle with a data acquisition system on board was used to obtain data to validate the simulation. Straight line running tests with speeds from 20 km/h to 160 km/h were conducted. To stimulate weave oscillations a lateral force disturbance was applied via a sudden expansion of compressed air from a nozzle mounted on the motorcycle. Experimental and theoretical weave mode natural frequency and damping ratio as a function of speed were plotted as shown in Figure 4.16. Good correlation is noted at speeds greater than 100 km/h. Discrepancies at lower speeds were said to be due to more intense rider control activity. Higher speed operation was said to be more nearly 'open loop'.

To analyze the handling behaviour, Chenchanna and Koch (1979) conducted a series of tests using entry to and exit from 90° of a 50 m radius curve. They proposed use of a 'Handling Index' (H.I.) to characterize handling as defined below:

$$H.I. = - \hat{M}/\dot{u}\hat{\dot{p}}$$

where $\hat{M}$ = peak value of steer torque
  $\dot{u}$ = forward velocity
  $\hat{\dot{p}}$ = peak value of roll velocity
For speeds greater than 50 km/h, H.I. = I_3/R_V
  where I_3 = front wheel moment of inertia
    R_V = rolling radius of front wheel

Apparently the H.I. was chosen to characterize handling on the basis that the rider has a limited capacity to apply steer torque.

Figure 4.17 shows H.I. as a function of speed. Figure 4.18 gives maximum curve-negotiating speeds for various values of H.I.
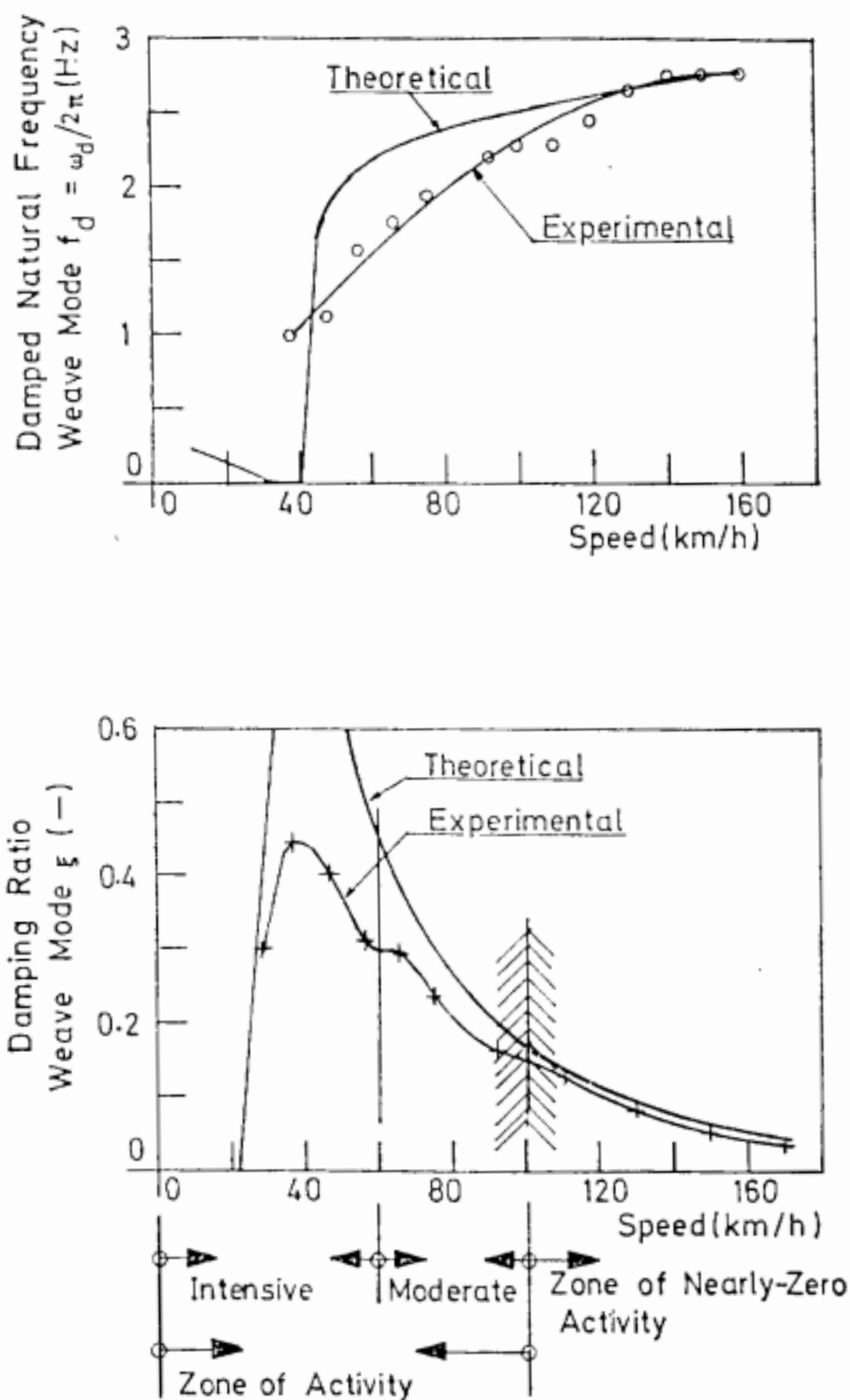
Figure 4.16 Experimental and theoretical weave mode
natural frequency and damping ratio as a
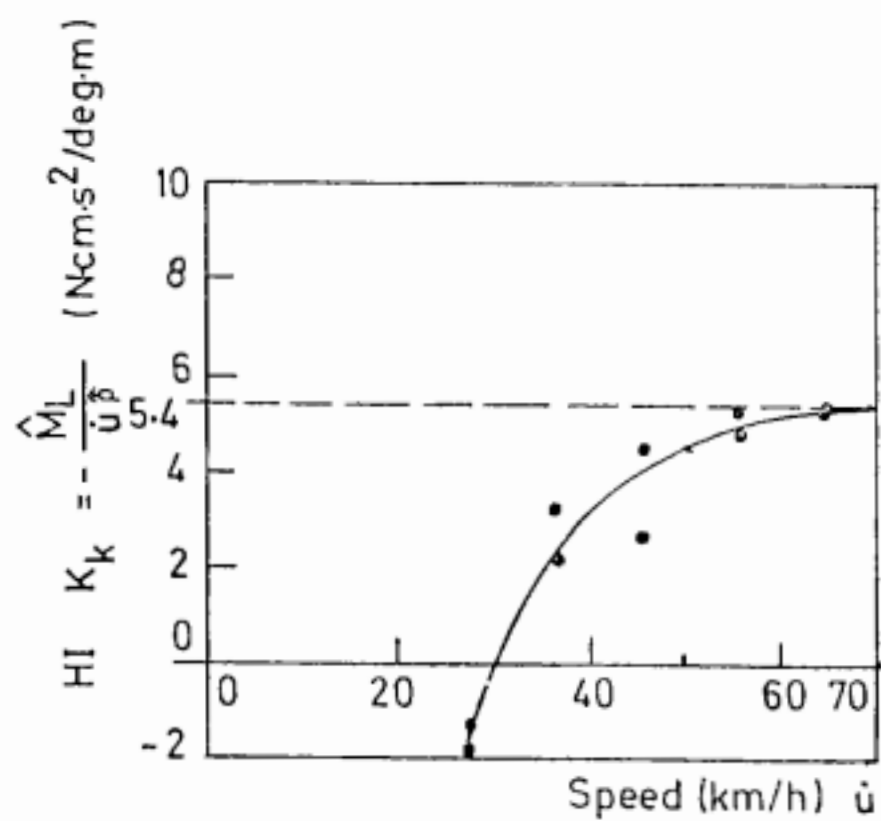function of speed (Chenchanna and Koch, 1979).

Figure 4.17 Handling Index (HI) as a function of speed
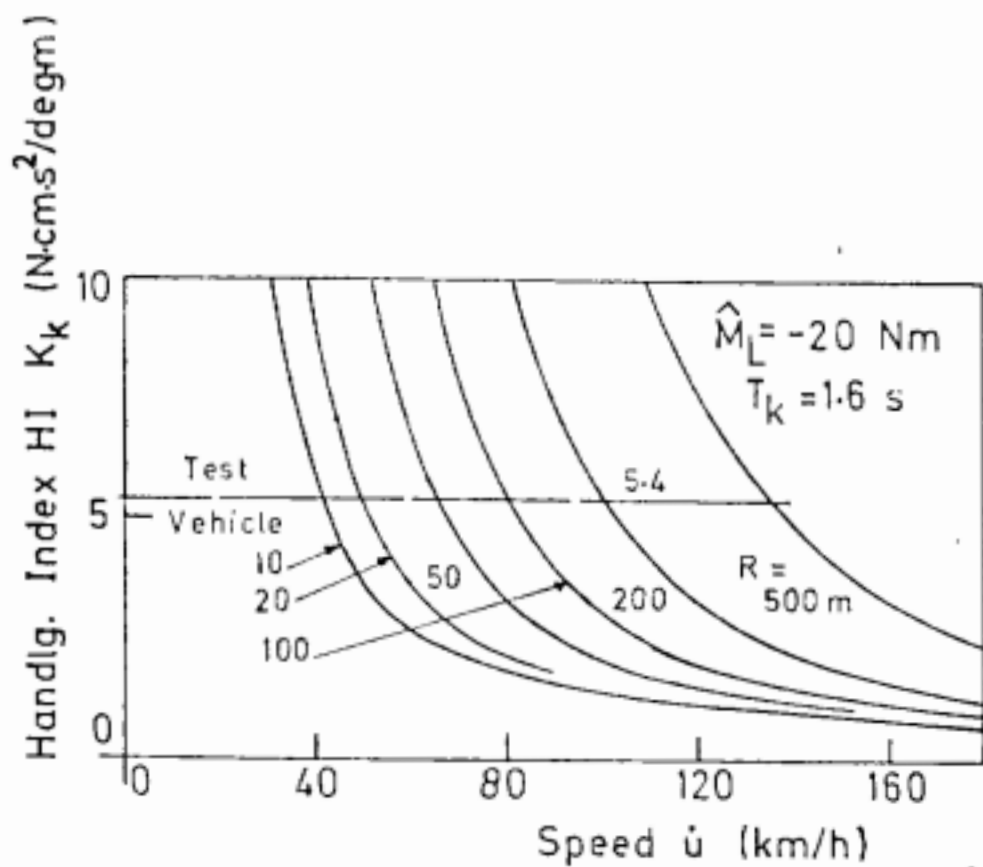(Chenchanna and Koch, 1979).

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Figure 4.18   Maximum curve negotiating speed versus
Handling Index (HI) (Cherchanna and Koch, 1979).

based on a constant peak torque. A low H.I. gives a higher curve negotiating speed. However, no real justification for this particular choice of a handling index was presented.

The experimental investigiations of rider/motorcycle performance reviewed here have made attempts at defining appropriate handling parameters to describe motorcycles. However motorcycle behaviour and rider/motorcycle interactions are still not well understood, and further research is required. Handling characteristics need to be defined so that what constitutes a 'good' handling motorcycle is known. This would then allow the interaction of handling behaviour and accident involvment to be investigated, and the assessment of the effects on handling qualities of various motorcycle modifications.

4.3 ANECDOTAL EVIDENCE OF BRAKING STABILITY AND HANDLING PROBLEMS WITH CURRENT MOTORCYCLES

Motorcycle magazines from Australia, Great Britain and U.S.A. were reviewed in order to further investigate braking, stability and handling problems encountered with currently available machines. The information obtained primarily originated from road test reports.

To assess braking, stability and handling performance of a particular motorcycle, the road tester typically covers 1000 to 2000 km through all types of terrain and conditions; i.e. commuting in heavy traffic, touring over long distances, and race track limit manoeuvres. The handling of the motorcycle is then subjectively rated on its performance in lane changing, negotiation of S-bends, low speed manoeuvring ability in traffic situations, and high speed stability.

The British magazine *Motor Cycle Mechanics* and the American magazine *Cycle World* report the results of this testing by way of verbal description. Problematical behaviour is usually described

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in journalistic and jargon terms which can make interpretation difficult, e.g.:

> 'At speeds reasonably attainable on the street, the machine feels much lighter than it is and is surprisingly neutral in handling.'
> (Anon, *Cycle World*, Vol. 18, No. 1)

> 'Handling through fairly fast country roads felt good, too. Apart from a tendency for the steering head to nod from side to side on some corners, the machine was stable and predictable.'
> (Anon, *Motor Cycle Mechanics*, Sept. 1979)

The Australian magazine *Two Wheels* presents, in tabulated form, the subjective ratings given under various handling and braking headings; two examples are shown in Figure 4.19. The ratings range from poor through to outstanding with a total of eight increments. Unfortunately the headings used are not easily interpreted; e.g. what does 'steering' actually mean, and how is this quantity assessed? Furthermore it is not clear what constitutes an 'average' rating. An analysis of twenty-three of these report summaries, published over a period of 18 months, indicated that the mean subjective rating in each category was 'above average'.

The distributions of the ratings of handling and braking qualities are shown in Figure 4.20. It can be seen that there is a fairly wide range of ratings for each attribute. The most severe judgement was generally 'below average', with some bikes bordering on 'poor.' The (low speed) manoeuvring quality was the only one to attract ratings of 'poor.' At the other end of the scale, motorcycles were rated as 'outstanding' in every category except braking in corners.

It is of interest that the ratings of the various handling attributes of a given machine were generally highly correlated. This would suggest either a 'halo effect' in the raters' assessments, or that 'outstanding' top speed stability, for example, can be achieved without compromising manoeuvrability. The latter interpretation suggests that it should be possible to design a motorcycle which is 'outstanding' in all respects. According to one reviewer, the machine rated in Figure 4.19 (b) comes close to this ideal.

The most serious problems encountered by road testers were high speed weaves, high speed wobbles, slow response at low speed, self steering and roll limits imposed by foot pegs, mufflers and stand brackets. It is emphasized that these problems are not common to all motorcycles, nor do they necessarily all occur with a particular motorcycle. Furthermore, some only become obvious when speeds far in excess of the legal limit are attempted. However they do exist with some machines. An example of weaving and wobbling behaviour:

> 'Setting the shocks up to a maximum preload helped, but the machine still wallowed and wobbled in turns at speeds above 160 km/h and was particularly upset by bumps and road irregularities after a few laps at that speed. The rider had to be very careful with the throttle exiting turns, especially bumpy turns, or else a combination of inadequate shock damping and losing and regaining rear tyre traction threatened to send the machine into tank slappers.'
> (Anon, *Cycle World*, Vol. 18, No. 1, 1979)

An example of slow low-speed steering response:

> 'Along with the superb high-speed handling buyers will have to put up with this maker's traditionally heavy low-speed steering and slow low-speed responses
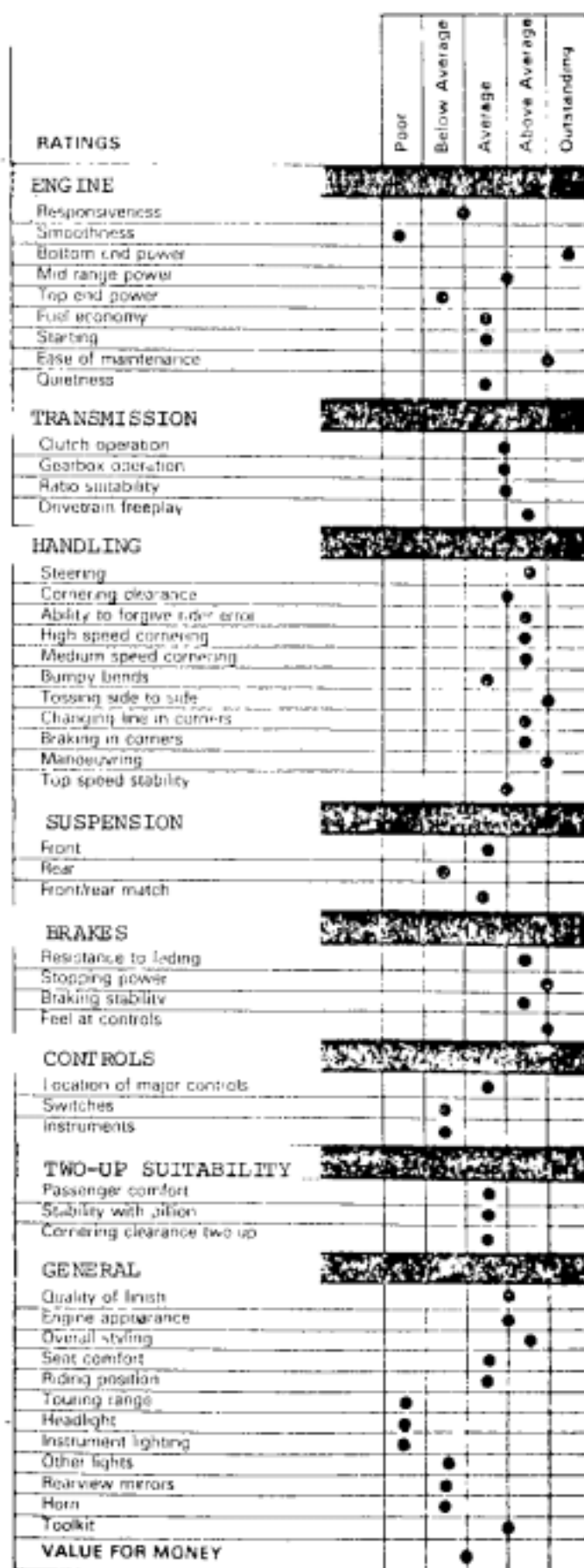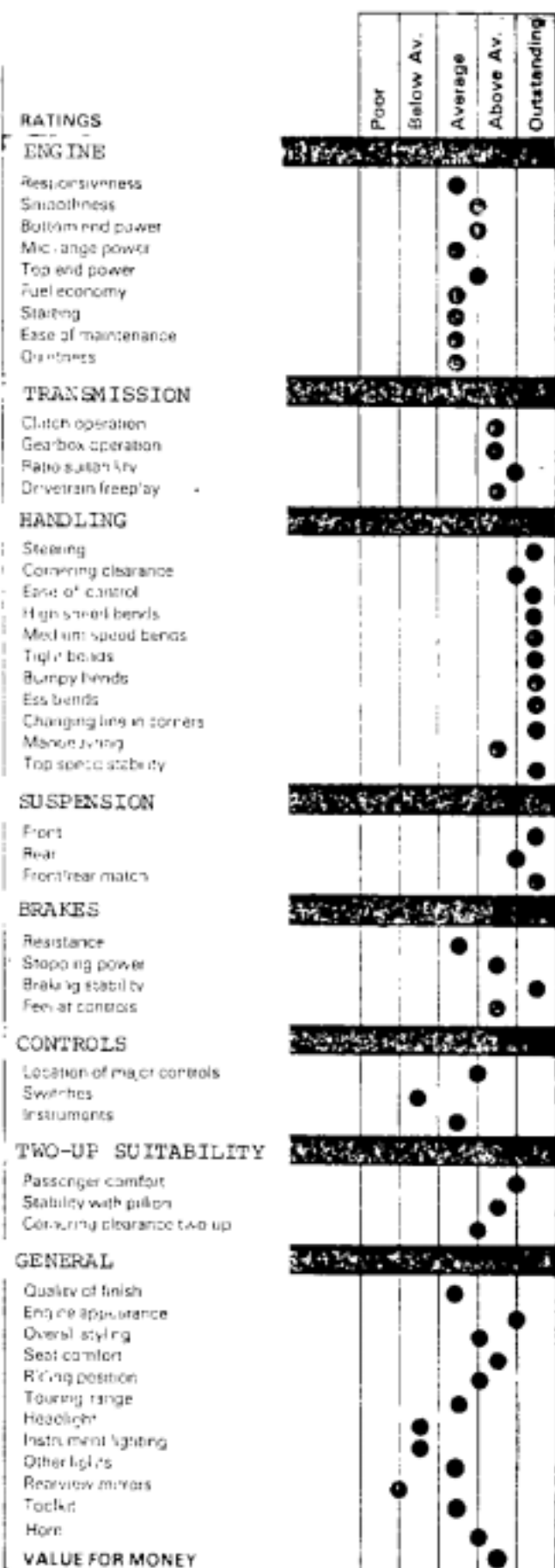
Figure 4.19   Subjective ratings of motorcycle
performance (*Two Wheels* June 1977, March 1979).

Figure 4.20 Distribution of ratings given for handling and braking qualities (source: *Two Wheels*, June, 197* to December 1979).

as well as the usual annoying lack of steering lock
(because maker mounts its forks in very narrow triple
clamps they come back and touch the tank quite
early).'

(Anon, *Two Wheels*, January, 1979)

The following report is of a motorcycle with inadequate
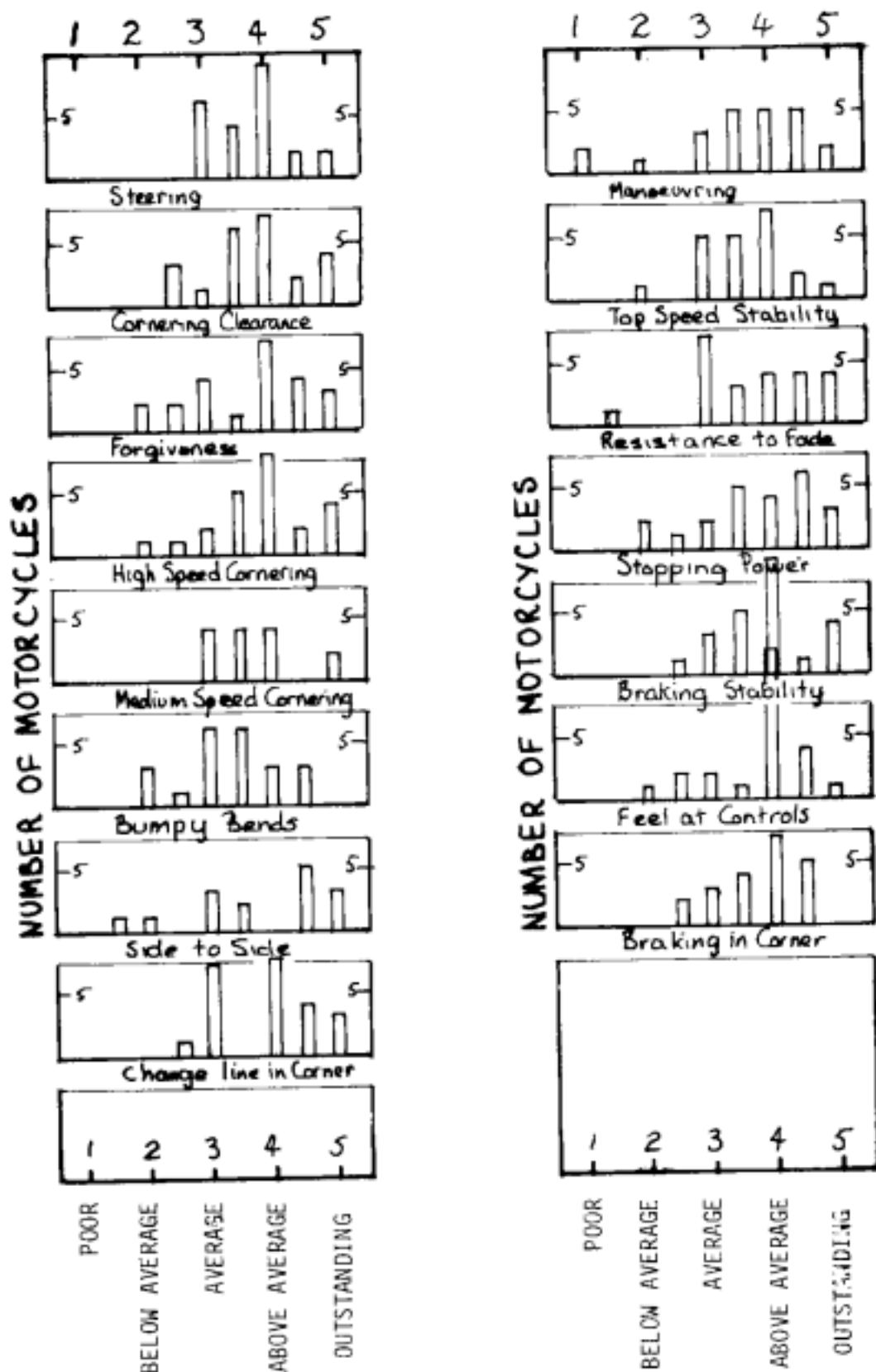ground clearance for roll angle limits:

'Handling and steering, while heavy, were firm and
positive. The only time the 1200 ml machine got
upset was when I let it ground by going through a
bumpy bend faster than I should've. Then it leapt up
and twitched across the road. It would ground
easily, many degrees before most other machines...'
(Anon, *Motor Cycle Mechanics*, August 1978)

A further example of a handling problem is in a report of a
road test on an 1100 ml machine. The variation of steering
characteristics with different tyres is noted:

'The steering of the machine was affected
considerably by the tyres fitted. With the Metzeler
on the front the machine was a huge self-steerer
(more so than any other bike we've ridden), but with
the Avon on the front the self-steering tendencies
were much reduced. The bike could be more accurately
manoeuvred at low to medium speeds so the Roadrunner
tyres certainly suited the bike more. It was
surprising a front tyre alone could make such a
difference.'
(Anon, *Two Wheels*, November, 1978)

The preceding text serves to give an indication of some of
the stability and handling problems test riders have reported
with new motorcycles. It would appear that most riders find the

stability and handling behaviour of a new motorcycle to be satisfactory under normal riding conditions. However it seems the behaviour of the machine deteriorates with age and distance covered. An important contribution towards elucidating some of these problems has been made by the Australian importing agent for Metzeler tyres (Anon, 1979). Unfortunately the 'problems' are not specified or defined, so it can only be assumed that weaving, wobbling and change of steering behaviour are implied. The report is as follows:

'After monitoring some 200 motorcycles over the past few months whose owners complained of some type of handling difficulties, we collated some rather terrifying statistics, 90% of machines had out of balance wheels, 85% had inadequate tyre pressures for operating conditions and 94% of wheels were out of alignment.

These figures closely approximate figures obtained in recent surveys conducted in the U.S.

Eliminating these three major faults, corrected the handling problems in 95% of the machines. The balance of handling complaints were traced to faulty suspension action, worn steering head and swing arm bearings, and bushes and bent frames.

The point is loud and clear. Any motorcycle, but particularly those operated at high speed, should have these areas thoroughly checked at regular intervals.

Every motorcycle manufacturer issues details of correct tyre pressures for their machines. Wheels should be balanced, obviously, whenever a new tyre is

fitted and subsequently every 3000 kms.

Wheel alignment should be carried out every time a
wheel is replaced on the motorcycle.'

A further source of evidence of the existence of stability and
handling problems is the user correspondence published by
motorcycle magazines. As an example a letter published in *Motor
Cycle Mechanics*, February, 1978 said:

'I am writing to you in the hope that my experience
may help by warning others. In mid-September I bought
a top half sports fairing with pouches to extend over
the handlebars...With fairing fitted properly I set
off to work as usual but noticed a little instability
about the handlebars and front wheel at around 110
km/h, but this disappeared when I leaned forward.
Coming home at 120 km/h the wobble returned. It was
as if the front wheel was being lifted and the
handlebars being shaken from side to side. I shut
the throttle and the bars went onto full lock and
threw me up the road, breaking bones in my wrists
and hands and resulting in stitches in the knee and
hand. I was lucky I wasn't run over.

Although my bike... also has a top box fitted, it has
never before shown the slightest handling problem,
and the police could find nothing wrong with it when
they examined it after the accident. While I
appreciate that the accident could have been caused
by some unknown factor I believe the fairing was to
blame.'

This letter resulted in *Motor Cycle Mechanics* being flooded with
reader complaints of a similar nature, particularly from those
who had fitted handlebar fairings. The magazine conducted an
experimental program aimed at identifying the problems. The

TABLE 4.1   PERFORMANCE OF MACHINES WITH VARIOUS LOADS
CARRIED (*Motor Cycle Mechanics*, June 1978)

PERFORMANCE TEST DATA

Yamaha RD250													Kawasaki Z650			
Test	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Weight carried	Empty	10lb	30lb	60lb	75lb	80lb	85lb	106lb	162lb	Empty	40lb	Parts off	Empty	70lb	70lb	Parts off
Lap time (all + 1min)	37.5s	30.8s	29.9s	33.3s	32.5s	31.7s	34s	34.5s	54s	30.4s	33.1s	31.3s	29.5s	31s	—	—
Top speed mph	85	85	85	85	83	83	83	83	79	85	85	85	107	106	—	100

TABLE 4.2   PERFORMANCE OF MACHINES WITH DIFFERENT
FAIRINGS (*Motor Cycle Mechanics*, August 1978)

MAXIMUM SPEEDS (MPH)

MACHINE	Unfaired	OF Sports	OF Touring	HoW Monza	HoW Tourer	HoW Stingray	HoW Hawk	GP Sports	GP Tourer
KAWASAKI 400	98	93.5	87.5	98					
HONDA 400-4	106				97	103	104		
YAMAHA 250	89.5		81	88.5				89.5	73.5

first tests were done on top boxes and panniers, and they found that almost any amount of weight could be carried without seriously degrading handling behaviour. Test results are shown in Table 4.1. The second investigation was of the influence of fairings on stability. It was found that handlebar fairings had little effect on the stability of the motorcycles during the experiments. The results are given in Table 4.2. These apparently unexpected results are possibly more a reflection of the method of analysis used rather than conclusive evidence of no effects.

Magazine road test reports also serve to highlight braking problems with current motorcycles. Many different problems are encountered, including: brakes that are too powerful, enabling wheels to be easily locked; brakes that are under-powered; lack of stopping power for disc brakes in wet conditions; slow response of disc brakes when wet; and control gains of the braking system not appropriate to the task. Following are three extracts from road test reports. These are examples that have been selected to be representative of brake problem areas.

First, from a road test of a 750 ml machines:

> 'While the front and rear brakes were quite well
> balanced for heavy braking, the machine wasn't so
> good under less strenuous conditions when more use
> was made of the rear brake. Its often convenient
> to drag the rear brake to scrub off speed while the
> bike is banked over, or while manoeuvring through
> traffic and in these conditions the drum brake
> could have done with more power. Towards the end
> of the test the front discs started to squeal under
> light braking but they kept up their performance
> and apart from a slight lag at very low speed
> worked well in the rain.'
> (Anon, Motor Cycle Mechanics, July, 1979)

The second extract comes from a road test report for a 400 ml
machine:

> 'Braking is a mixed bag. The numbers arn't too bad;
> 11 m from 50 km/h and 48 m from 100 km/h. But under
> hard braking the rear of the bike hops easily when
> the brake locks, making control difficult. The front
> brake provides good control but it is not powerful
> for a disc. In wet weather only the rear brake slows
> the bike, the front washing out completely and being
> slow to recover.'
>
> (Anon, *Cycle World*, Vol 18, No. 1, 1979)

The final extract is from a road test of a 650 ml machine:

> 'To be frank, the braking system...is an overkill.
> Triple disc brakes on a machine of this weight and
> performance...? Not only does the bike stop quickly
> it also locks up wheels easily, especially the front
> one. That's unnecessary and potentially hazardous...
>
> The biggest problem with a pure disc brake
> arrangement is the wet weather performance and the
> (machine) stopped as expected in rainy conditions –
> badly. At some stages it felt like it had no brakes
> at all...'
>
> (Anon, *Two Wheels*, January 1979)

4.4   CONCLUSIONS

(i)   The study of motorcycle-alone lateral dynamics has
       received considerable attention in the literature over the
       past decade. The models developed appear to give
       reasonable correlation with actual behaviour, but further
       experimental validation is required. Useful design con-
       clusions have been drawn from these studies.

(ii) The lack of emperical data for motorcycle tyres, and over-simplified modelling of tyres, is thought to be the main cause of discrepancies between theoretical and experimental lateral dynamic behaviour.

(iii) Three physically significant natural modes have been identified from linear mathematical models of the lateral dynamics of the motorcycle. These have been designated as the wobble, weave and capsize modes. For some design configurations and forward speeds the weave and wobble modes may become unstable, and their natural frequencies are too high to allow the rider to control them. For most machines the capsize mode is unstable at normal traffic speeds, thus requiring continuous control activity by the rider.

(iv) The dynamics of the closed loop rider/cycle system are much less well understood than the cycle-alone dynamics. Motorcycle/rider simulations are available which include non-linear representation of the motorcycle dynamics so as to allow for the large roll angles experienced in various manoeuvres. Considerable further work, however, is required to establish appropriate rider control strategies and parameters.

(v) Experimental studies have shown that, contrary to some popular belief, motorcycles are no more 'manoeuvrable' than automobiles in obstacle avoidance situations.

(vi) Motorcycle size, as such, does not appear to have an important influence on the obstacle avoidance performance of the rider/cycle system. On the other hand, rider skill variations lead to substantial differences in evasion distances required to successfully avoid obstacles in the motorcycle's path.

(vii)   At normal traffic speeds, evasive manoeuvring appears to
        be a better accident-avoidance strategy than braking.

(viii) Little progress has been made in identifying the important
        features of a motorcycle's dynamic response which deter-
        mines its 'handling quality'.

(ix)   There is a considerable amount of anecdotal evidence
        suggestive of braking, stability and handling problems in
        the popular motorcycling press. Examples cited include
        high speed weaves and wobbles, poor brakes in both wet and
        dry conditions, slow steering response at low speeds,
        tyres influencing motorcycle behaviour to a large extent,
        and fairings upsetting high speed stability. There is a
        need for further research to improve the level of under-
        standing of motorcycle-rider interactions so that such
        problems can be reduced and so that desirable handling
        properties can be quantitively specified.