1974

Calspan

SIXTH MONTHLY PROGRESS REPORT

1 December 1974 - 31 December 1974

TO: National Highway Traffic Safety Administration

Contract DOT-HS-4-00976

Project No. ZN-5571-V

"RESEARCH ON THE ACCIDENT AVOIDANCE CAPABILITIES OF MOTORCYCLES"

PROGRAM OBJECTIVES

The overall objectives of this research effort are:

1. To develop a set of motorcycle accident avoidance test procedures and to define the meaningful objective response parameters that can be used to quantify accident avoidance capability.

2. To evaluate the accident avoidance capabilities of a representative sample of motorcycles using the accident avoidance test procedures in a computer simulation.

Calspan Corporation
Buffalo, New York 14221

1. WORK PERFORMED DURING REPORTING PERIOD

Task 3 - Motorcycle Parameter Measurement

During this period, data on the physical parameters of the Kawasaki F-11 were obtained. Measurements were made, however, on a Kawasaki F-7, since it was immediately available. The two motorcycles are similar Enduro-type machines, the principal difference being engine size. The F-11 has an engine displacement of 247 cc and weighs 264 lbs. while the F-7 has a 174 cc engine and weights 239 lbs. The physical configuration of the two motorcycles is similar, with the major dimensions of the F-11 approximately 5% greater than those of the F-7. The complete data set to be used for the F-11 is shown in Table 1. Wheel tire data were taken from the F-11 components we have on hand, and the inertia values measured on the F-7 were increased 5-10% to approximate those of the F-11.

Table 2 gives the measurements previously made on the Harley-Davidson FLH-1200 which will also be used in this program.

The remaining tires needed for testing were obtained during this reporting period. The adapters needed to mount the motorcycle wheels to the tire test machine were completed and tire testing is currently in progress. The tire test matrix is that presented in the Plan of Work. Tests are to be performed at 100% and 120% of mounted tire load with a 150 lb. rider. Recommended tire pressures are used in all cases. A summary of tire normal loads and inflation pressures are given in Table 3.

We have not been able to obtain commitments for the use of either the 1972 Yamaha XS2 650 or the Norton Commando Roadster. In the case of the Yamaha, we have not been able to locate an owner willing to rent or loan such a motorcycle but will continue this search. Repeated contacts with the only local Norton dealer have been unsuccessful in locating a machine of this type. It therefore appears that we will need the assistance of NHTSA in procuring data on these two motorcycles.

TABLE 1
MOTORCYCLE PHYSICAL CHARACTERISTICS

Motorcycle Kawasaki F11 250

1.	Wheelbase	54.6	in.
2.	Seat Height from Ground	32.1	in.
3.	Front Tire Size	3.00x21	
4.	Rear Tire Size	4.00x18	
5.	Front Tire Outside Diameter	27.68	in.
6.	Rear Tire Outside Diameter	26.42	in.
7.	Fork Tube Angle	60.0	Degrees
8.	Fork Tube Offset	2.45	in.
9.	Weight of Rider	150	lbs.
10.	Front Wheel Load without Rider	116	lbs.
11.	Rear Wheel Load without Rider	156	lbs.
12.	Front Wheel Load with Rider	155	lbs.
13.	Rear Wheel Load with Rider	267	lbs.
14.	Weight of Front Wheel and Tire	22.0	lbs.
15.	Weight of Front Assembly (Handlebars, front fork, fender, wheel and tire)	60.0	lbs.
16.	Front Suspension Ride Rate	60	lbs./in.
17.	Rear Suspension Ride Rate	330	lbs./in.
18.	Distance of Total Motorcycle C.G. from Ground	21.5	in.
19.	Perpendicular Distance from Steer Axis to Front Assembly C.G.	0.40	in.
20.	Distance from Front Assembly C.G. to Wheel Center Along Line Parallel to Steer Axis	14.5	in.

TABLE 1

MOTORCYCLE PHYSICAL CHARACTERISTICS (Contd.)

21.	I_{yy} of Front Wheel and Tire	4.95	lb-in-sec^2
22.	I_{xx} of Front Assembly	34.1	lb-in-sec^2
23.	I_{zz} of Front Assembly	5.80	lb-in-sec^2
24.	I_{xx} of Total Motorcycle	63.3	lb-in-sec^2
25.	I_{zz} of Total Motorcycle	242	lb-in-sec^2

TABLE 2

MOTORCYCLE PHYSICAL CHARACTERISTICS

Motorcycle Harley Davidson FLH 1200

1.	Wheelbase	61.5	in.
2.	Seat Height from Ground	28.6	in.
3.	Front Tire Size	5.10x16	
4.	Rear Tire Size	5.10x16	
5.	Front Tire Outside Diameter	26.40	in.
6.	Rear Tire Outside Diameter	26.40	in.
7.	Fork Tube Angle	28.2	Degrees
8.	Fork Tube Offset	1.44	in.
9.	Weight of Rider	150	lbs.
10.	Front Wheel Load without Rider	300	lbs.
11.	Rear Wheel Load without Rider	490	lbs.
12.	Front Wheel Load with Rider	339	lbs.
13.	Rear Wheel Load with Rider	601	lbs.
14.	Weight of Front Wheel and Tire	41	lbs.
15.	Weight of Front Assembly (Handlebars, front fork, fender, wheel and tire)	128	lbs.
16.	Front Suspension Ride Rate		lbs./in.
17.	Rear Suspension Ride Rate		lbs./in.
18.	Distance of Total Motorcycle C.G. from Ground	17.9	in.
19.	Perpendicular Distance from Steer Axis to Front Assembly C.G.	1.90	in.
20.	Distance from Front Assembly C.G. to Wheel Center Along Line Parallel to Steer Axis	17.9	in.

TABLE 2
MOTORCYCLE PHYSICAL CHARACTERISTICS (Contd.)

21.	I_{yy} of Front Wheel and Tire	7.20	$lb\text{-}in\text{-}sec^2$
22.	I_{xx} of Front Assembly	69.0	$lb\text{-}in\text{-}sec^2$
23.	I_{zz} of Front Assembly	16.4	$lb\text{-}in\text{-}sec^2$
24.	I_{xx} of Total Motorcycle	226	$lb\text{-}in\text{-}sec^2$
25.	I_{zz} of Total Motorcycle	1000	$lb\text{-}in\text{-}sec^2$

TABLE 3

TIRE TESTING - NORMAL LOADS AND TIRE PRESSURES

Tire No.	Tire Size	Application	Test Loads (lbs)	Test Pressure (psi)
1	2.75-18	Honda 125 Front	125	26
			150	
2	3.00-17	Honda 125 Rear	230	28
			275	
3	3.00-18	Honda 360 Front	210	26
			250	
4	3.50-18	Honda 360 Rear	315	28
			380	
5	3.50-19	Yamaha Front	240	23
			290	
6	4.00-18	Yamaha Rear	360	28
			430	
7	3.00-21	Kawasaki Front	155	24
			185	
8	4.00-18	Kawasaki Rear	265	31
			320	
9	4.10-19	Norton F & R	215	24
			260	

Task 4 - Test Procedure Development

Test Development

Investigation of the suitability of various response tests was continued during the period with emphasis on selecting a method which is compatible with the Calspan computer simulation. Further effort was also applied toward defining a single complementary maneuvering task which would be useful for studying rider skill effects. These two procedures will be used for the in-depth studies of the handling/accident avoidance qualities of the six motorcycles being evaluated. It is recognized that braking characteristics are not covered in this approach, but we believe that extension of the simulation studies to include detailed investigation of this aspect of performance would compromise the degree to which the directional control characteristics can be studied. We do intend, however, to experiment with braking effects in the full-scale tests and to present recommendations on testing in this mode.

In last month's report, it was indicated that a form of the constant radius test method was being given first consideration. Although this procedure appears to be reasonable for full-scale experimentation, it imposes more stringent requirements on the simulation than do methods which are fundamentally constant speed tests. Inasmuch as the simulation will be used as the primary means for evaluating five of the six motorcycles to be studied, it is essential that satisfactory compatibility be assured. For this vehicle response type of test, minimization of driver influence, both in full-scale and with the simulation, was therefore taken as a high priority criterion.

It should be understood that the vehicle simulation in its present form is most efficient in a mode of operation calling for approximately constant speed and preprogrammed control inputs applied to an initial condition of straight ahead trim. The rider model is required to process only the information necessary to maintain roll stability under these conditions. Guidance functions (path maintenance and heading) are minimized and the need to determine proper values for path and heading motion feedback terms is avoided.

The following factors were used in selecting a basic test procedure for vehicle response measurements -

1. Compatibility with simulation

   - for validation purposes
   - modification requirements
   - cost of operation
   - dependence on rider model

2. Full-scale test operation

   - coverage of performance range
   - instrumentation and equipment requirements
   - test area
   - control input coverage
   - cost of testing
   - test safety

On the basis of this evaluation (details of which can be made available), we recommend a modified constant speed/constant throttle procedure at two preselected conditions. This approach will permit acquisition of both transient and steady state response parameter values (in particular, lateral acceleration gains) for both steering angle and steering torque inputs and enable the computation of other parameters of potential interest (for example, motorcycle sideslip angles). In a slightly different form, this technique has been successfully simulated with the computer program. (See discussion under Task 5.)

The single lane change maneuver is currently being reviewed for suitability as the primary performance task with which to investigate rider skill influences. The questions of interest are concerned with defining course geometry for appropriate nominal test speeds, identifying the significant performance metrics and instrumentation requirements, and, again, examining compatibility of the procedure with capabilities of the simulation, particularly with respect to rider modeling requirements. It seems most practical to answer some of these questions in conjunction with preliminary full-scale experiments. These will be performed as weather conditions permit.

Other items of interest under this task are:

1. Instrumentation - all elements of the telemetering system have now been received and are being bench-checked. No problems have been encountered. Mounting chasses and protective enclosures are being fabricated to permit early evaluation and equipment familiarization in actual vehicle tests.

2. Additional procedures - some preliminary thought has been given to evaluating means for including braking performance in the full-scale tests but no definite recommendations can be made at this time.

3. Response parameter analyses - simplified linear expressions are being used to help in identifying pertinent performance factors in motorcycle evaluation. Some preliminary results are given in Appendix A. Continuing effort along this line is planned.

Task 5 - Motorycle Simulation

During this reporting period the simulation was exercised to determine its suitability to particular handling tests. Several runs were made, varying rider control model parameters to obtain good response characteristics. All the runs were similar to the one shown in Figure 1, which is a plot of the steer and roll angles obtained when the Harley Davidson FLH-1200 Electra Glide is maneuvered into a steady state turn at 40 mph. The motorcycle attains a steady state roll angle of approximately 22°, which corresponds to a lateral acceleration of 0.4g.

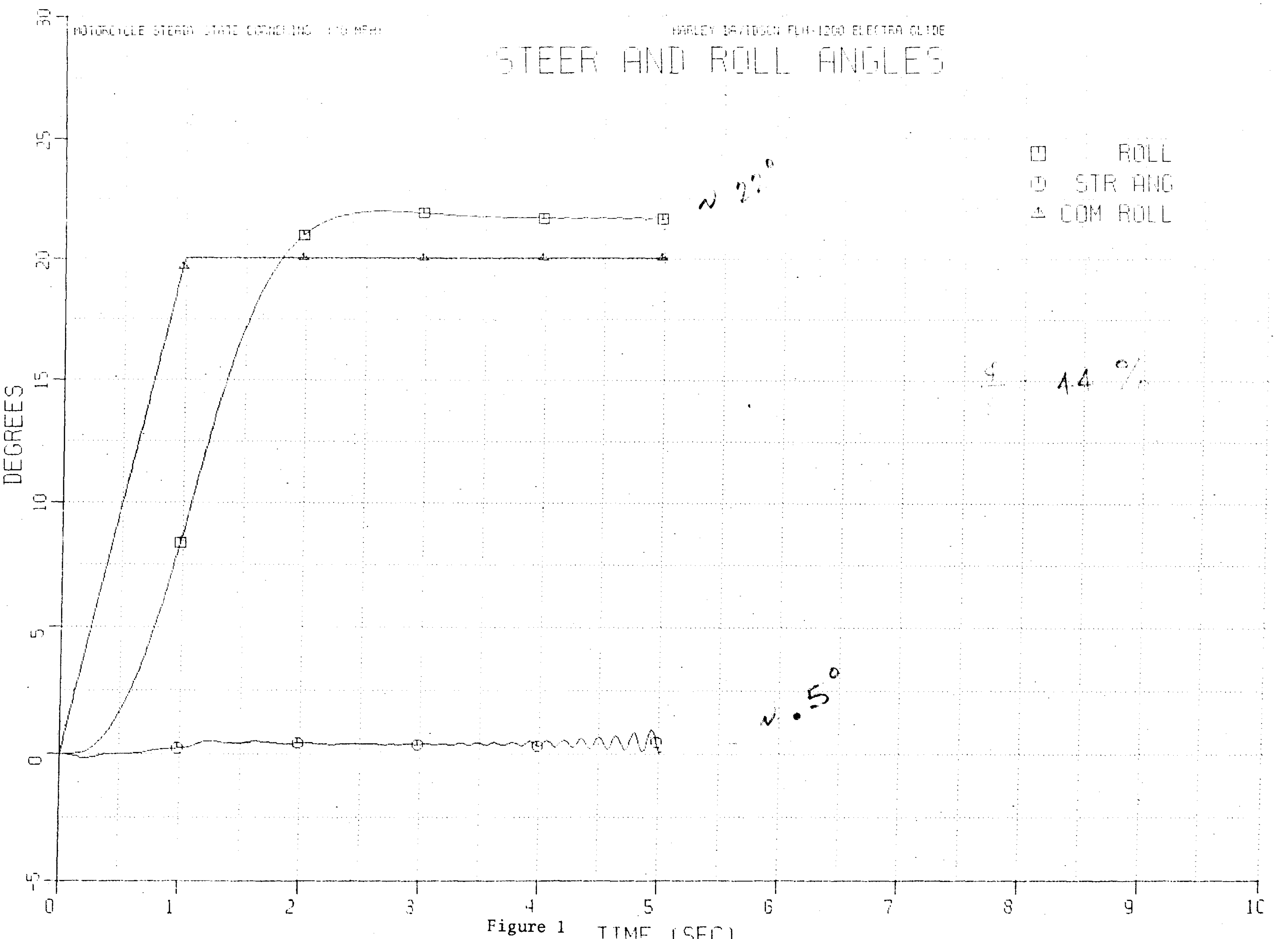

MOTORCYCLE STEADY STATE CORNERING (70 MPH)
HARLEY DAVIDSON FLH-1200 ELECTRA GLIDE
STEER AND ROLL ANGLES
ROLL
STR ANG
COM ROLL
DEGREES
TIME (SEC)
0
1
2
3
4
5
6
7
8
9
10
-5
0
5
10
15
20
25
30
~ 22°
~ .5°

Figure 1

From a series of plots such as this, the steady state position control parameters can be obtained, and the associated printed output (which can also be plotted) would yield the steering torque sensitivities. The rider's lean degree of freedom was effectively locked out in this run, but with the lean control operational, lean control sensitivity could be obtained as well. Each run in a series would specify a different steady state roll angle, each of which would correspond to a steady state lateral acceleration. By utilizing the simulation in this way, the transient can be kept fairly short, giving ample time for steady state conditions to be attained in the course of a five second simulation run.

On examination of Figure 1, a small amplitude, high frequency (7 Hz) oscillation will be noted in the steer trace. This may be due to the onset of a pitch oscillation, as was mentioned in the previous progress report. A more violent example of a pitch oscillation, which first demonstrated the possible need for a pitch damper, occurred during a run made previously. This run, shown as Figure 2, was at high speed (80 mph) with a prototype motorcycle. Because this severe oscillation occurred at a speed greater than that contemplated for use during this project, the addition of a pitch damper may prove unnecessary.

The two simulation runs included in this report are examples of the motorcycle simulation run using open loop command roll angle inputs. Briefly, what this means is that the rider model is told to place the motorcycle into a steady state turn in which the motorcycle is at a 20 degree roll angle. There is no attempt made to follow a specified path, as the path guidance function is taken out of the control loop.

The command roll angle is the output of the rider guidance model, as shown in Figure 3. The difference between the command roll angle, ϕ_c, and the motorcycle roll angle, ϕ, provides the error signal for the rider model stabilization function. The roll rate and roll acceleration feedback terms serve to stabilize the rider model. It is in the selection of the coefficients

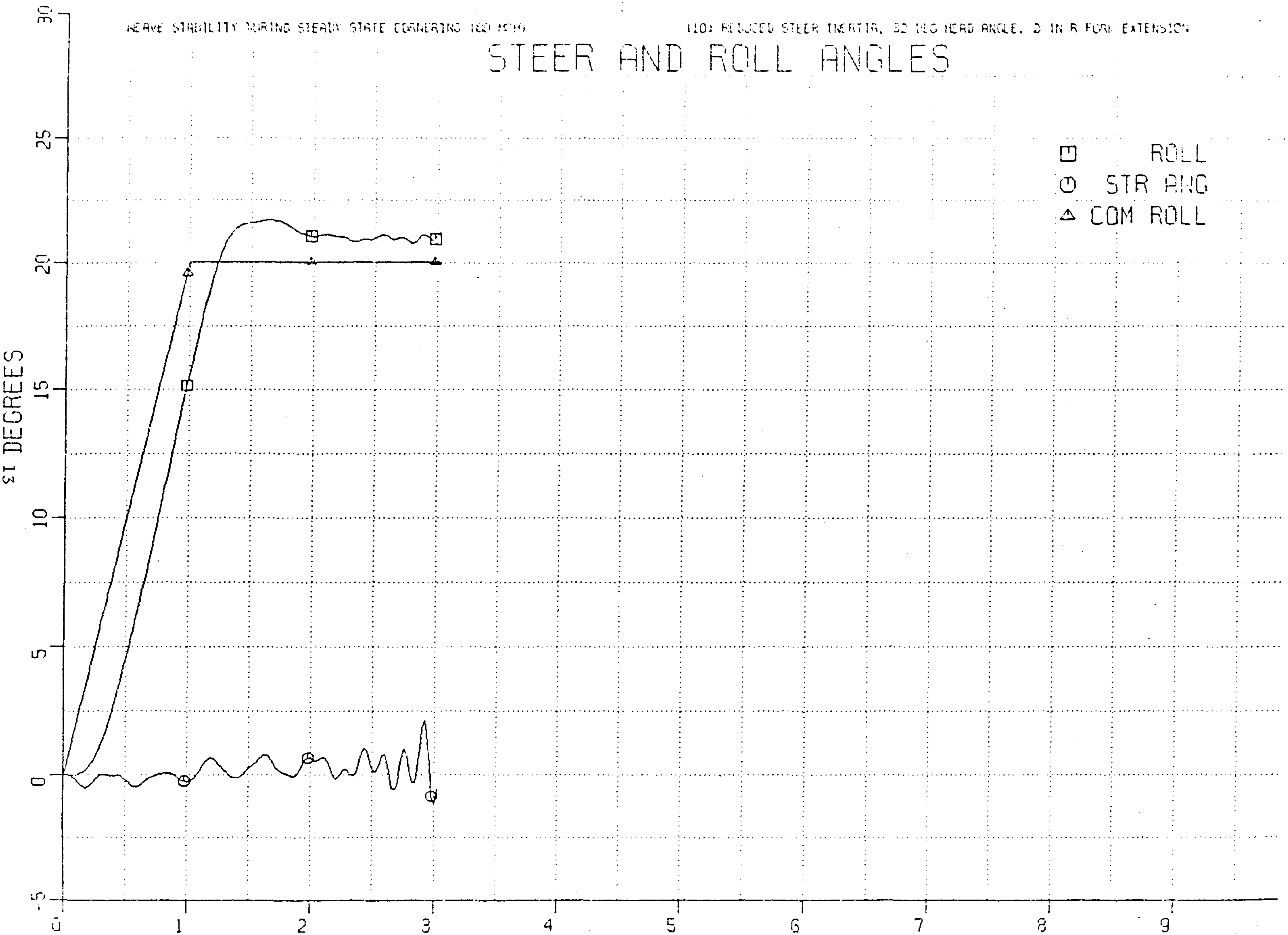
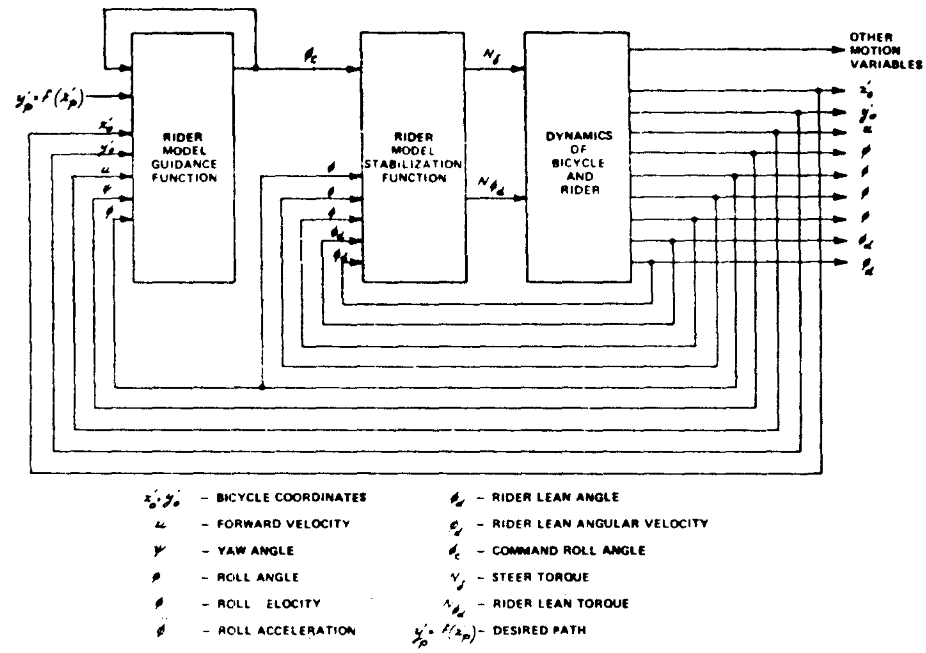
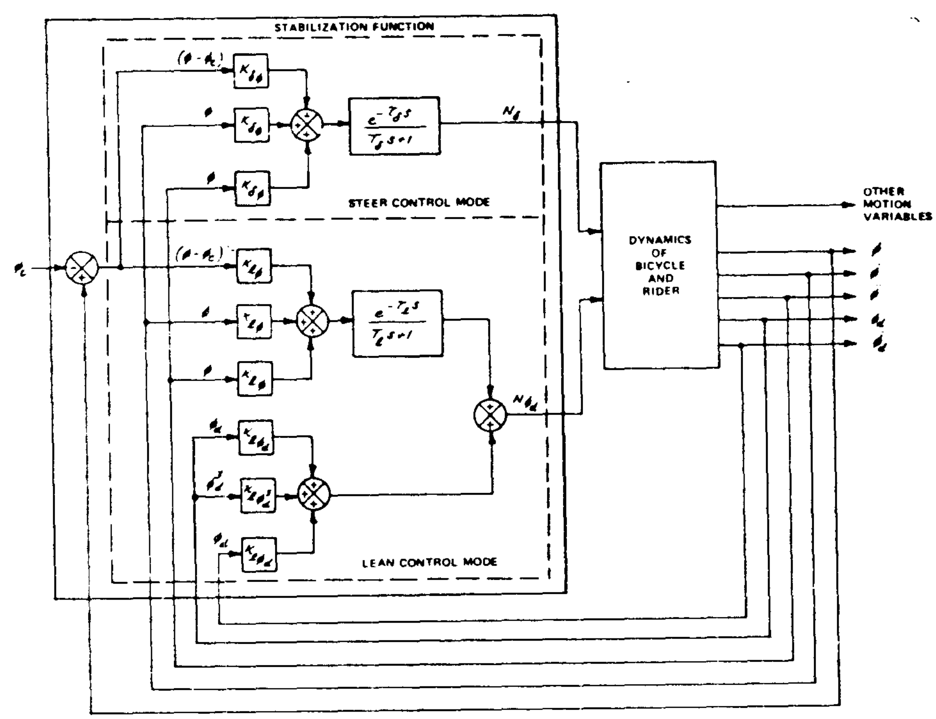

WEAVE STABILITY DURING STEADY STATE CORNERING (60 MPH)
(10) REDUCED STEER INERTIA, 32 DEG HEAD ANGLE, 2 IN R FORK EXTENSION
STEER AND ROLL ANGLES
ROLL
STR ANG
COM ROLL
DEGREES
30
25
20
15
10
5
0
-5
0
1
2
3
4
5
6
7
8
9
TIME (SEC)

Figure 2



Block Diagram of Bicycle Rider Control Model



Block Diagram of Stabilization Function of Rider Control Model

FIGURE 3

for these various feedback terms that problems occur, especially when changing from one motorcycle to another. Further work on this problem is planned for next month.

A more complete description of the rider stabilization function and the path guidance function can be found in Reference 2, from which Figure 3 was excerpted.

2. PROBLEMS AND PROGRAM SCHEDULE

The Project Schedule is shown at the end of this report. Work on Task 3 is still behind schedule but all effort on this task is expected to be completed by the end of January if the two remaining motorcycles become available, as indicated earlier under Section 1. The bulk of the effort on Task 4 is being held off until March (when full-scale tests can be conducted with reasonable continuity). In the interim, definition of test procedures will be continued. Full activity on Task 5, which is dependent in part on obtaining validation information, is being delayed until later in the program but the simulation is undergoing review and update so that it will be fully operational when required (approximately mid-March).

3. REQUEST FOR NHTSA ACTION

As noted in the discussion under Task 3, difficulties in obtaining the Norton and Yamaha motorcycles from local dealers for physical measurement have delayed completion of this task. We are therefore soliciting NHTSA help in obtaining the necessary data.

4. PLANS FOR NEXT REPORTING PERIOD

1. Tests of the nine tires are scheduled for the first week of the next period. Preliminary results of this testing will be available for discussion with the CTM by mid-month. The physical measurements of the two remaining motorcycles will be performed as soon as representative models can be obtained.

2. Activity on defining test procedures will continue with the aim of identifying and refining the procedures by the end of February (to be consistent with the full-scale testing work).

3. Work will continue on relating results of linear analyses of motorcycle performance with the full-scale test techniques and simulation requirements. Emphasis will be placed on discriminating among control input effects.

4. Increased activity on checking out all phases of operation of the simulation is planned. Principal items include representation of rider physical properties and sensitivity of response to rider control coefficients.

5. The mid-term briefing has been tentatively scheduled with the CTM for the first week in February.

Prepared by:

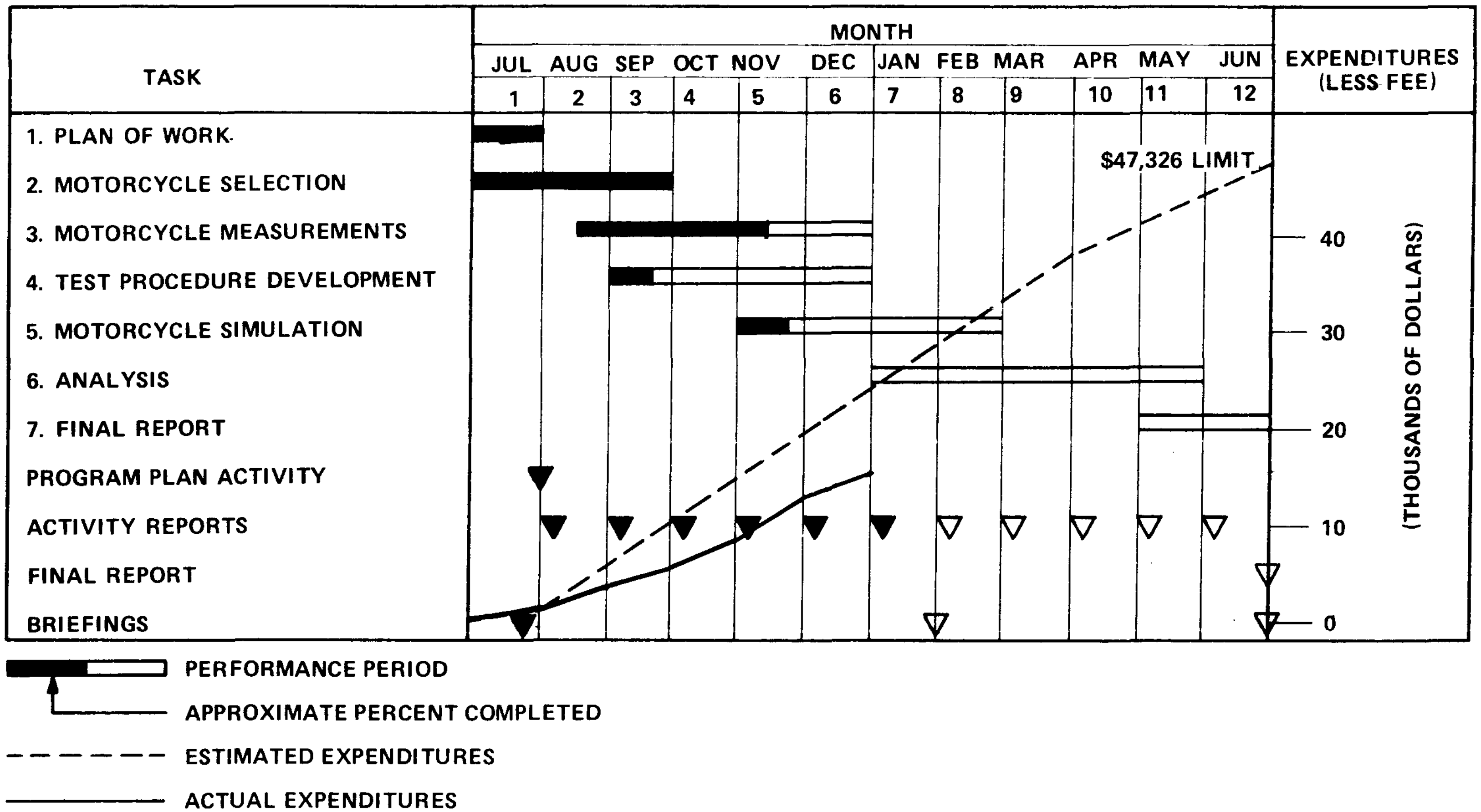
RsRice

Roy S. Rice
Project Engineer
Transportation Safety Dept.

Approved by:

RsRice for

F. Dell'Amico, Head
Vehicle Systems Section
Transportation Safety Dept.



PROJECT SCHEDULE - RESEARCH ON THE ACCIDENT
AVOIDANCE CAPABILITIES OF MOTORCYCLES

APPENDIX A
SIMPLIFIED RESPONSE COMPUTATIONS

As indicated in our previous progress report we are considering a directional control test of the type given in SAE XJ-266 for use with motorcycles. The 266 type of test, especially the constant radius version, is widely used with automobiles. Although relatively little has been published in the open literature (see, for example Reference 1), the physical parameters of the automobile that relate to these tests are well known. We, at Calspan, have done a considerable amount of work, in recent years, under the general heading of static stability of the automobile.

We know, for example, that the general relationship for the constant radius test is given by:

$$\delta = \frac{\ell}{R} - \frac{h}{C} \, Ay \qquad (1)$$

where δ = average front wheel steer angle
ℓ = wheelbase
R = radius of turn
Ay = lateral acceleration, g units

and the dimensionless parameters h and C relate to the basic physical constants of the automobile.

The understeer/oversteer factor, K, is given by

$$K = \left.\frac{d\,\delta}{d\,Ay}\right|_{R\text{-const}} = -\frac{h}{C} \text{ (in rad./g)}^{*} \qquad (2)$$

In the basic two-degree-of freedom model of a car the h parameter is the classic static margin - i.e. - $h = \frac{bC\alpha R - aC\alpha F}{\ell\,(C\alpha F + C\alpha R)}$ and C is a

* for a stable automobile h is always positive; C, on the other hand, is always negative ($C\alpha F$, R are, by definition, negative)

fundamental quantity, given by $C\alpha F\ C\alpha R/\ (C\alpha F + C\alpha R)\ W$.

In these expressions a & b are the front and rear axle distances to the c.g., W is total vehicle weight, and $C\alpha F,R$ are the tire cornering stiffnesses (#/rad.). When one starts with the basic 2df model (sometimes referred to as the bicycle model) and "adds on" steer effects by linear superposition one finds that such things as roll steer, roll camber, lateral force deflection steer, aligning torque deflection steer, and so on, merely "add on" to the h and C parameters of the 2df case. In this way we have been able to determine the influence of any one steer effect on understeer/ oversteer, K. For example, a typical large car may have an understeer factor of perhaps + 1°/g due only to cornering stiffness and c.g. location (i.e. as a 2df model) but when all steer effects are accounted for K will generally go up - to perhaps +6 or 7 °/g (positive K is understeer).

In the case of the motorcycle the question naturally arises: What are the physical parameters of the 2-wheeled machine that influence its steering properties?

We have, during the past year or so, developed the linear simplified theory for the 2-wheeled vehicle comparable to that already in existence for the car. The main reason for this approach is to gain insight into static and dynamic behavior that is difficult to acquire even with a sophisticated digital computer simulation. In any event, without going into the theory at this time, we wish to simply give some preliminary results on vehicle response parameters.

Our tentative results indicate that the equivalent of equation (1), sometimes called the skid pad equiation, for the motorcycle is:

$$\delta + \frac{C\alpha\phi}{C\sigma}\ \theta\ \phi\ R = \frac{\frac{\ell}{R} + \left(k\ C\alpha\phi - \frac{h_o}{C_o}\right) Ay}{C\sigma} \qquad (3)$$

In which -

δ = steer angle about the fork axis

ϕ_R = rider lean relative to the frame

$C_{\alpha\phi}$ = $\frac{C_{\phi F}}{C_{\alpha F}} - \frac{C_{\phi R}}{C_{\alpha F}}$ ($C_{\phi F,R}$ are tire camber stiffnesses)

$C_\sigma \cong \cos\sigma - \sin\sigma \frac{C_{\phi F}}{C_{\alpha F}}$ (σ is the complement of the fork tube angle)

θ = a rider lean angle gain that determines how much roll moment per unit lean (relative to the motorcycle frame) is obtained.

k = a term related to moments of inertia, it is $\cong 1$ and h_o and C_o are the same as they are for the 2df car (see above).

The interesting points that can be made about (3) are:

1. For zero rider lean (ϕ_R is pos. clockwise looking forward), the motorcycle is similar to the 2df car except that the apparent Ackermann angle (steer angle required as $V \to 0$ at constant radius) is $\ell/R \,/\, C_\sigma$ instead of ℓ/R - clearly a fork angle effect.

2. The understeer/oversteer factor, K, is

$$K\Big|_{mc} = \frac{k\, C_{\alpha\phi} - \frac{h_o}{c_o}}{C_\sigma}, \tag{4}$$

instead of

$$K\Big|_{car} = -\frac{h_o}{c_o} \tag{5}$$

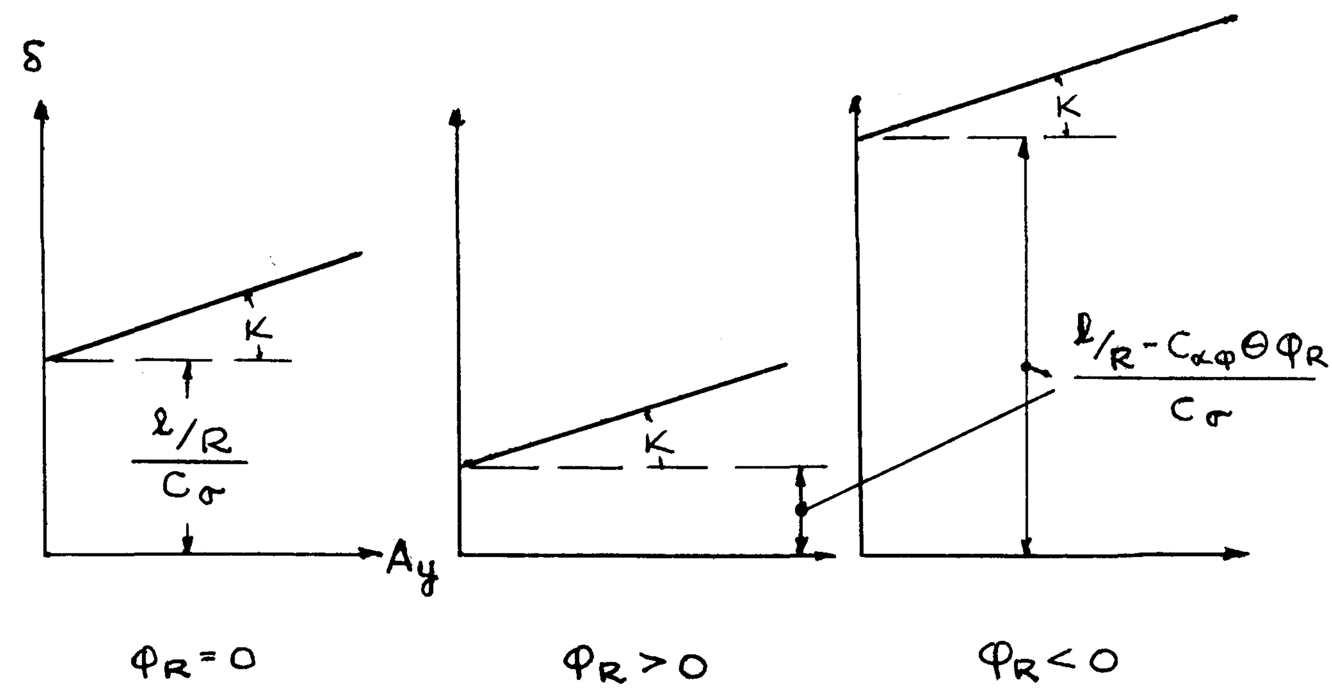
Again the fork angle effect is present but the turn $k\ C_{\alpha\phi}$ is similar to an "add on" steer effect in a car. In fact, it can be shown that the term is identical in effect to roll camber in a car.

3. The influence of rider lean, ϕ_R, is to change the apparent Ackermann angle but <u>not</u> the understeer factor, K. The Ackermann angle is given by (from equation 3):

$$\delta_A\Big|_{A_y = 0} = \frac{\ell/R - C_{\alpha\phi}\,\theta\,\phi_R}{C_\sigma} \qquad (6)$$

Positive lean (into the turn) will either increase δ_A or decrease it depending upon the sign of $C_{\alpha\phi}$. (C_σ and θ are always positive).

Skid pad plots for a motorcycle with positive K (one that is understeer) should appear as shown in the sketch: $(C_{\alpha\varphi} > 0)$



In other words a constant radius skid-pad test should reveal the understeer factor, K, regardless of rider lean angle - a result which is encouraging since we had earlier suspected that lean might "contaminate" the results.

As we have indicated these are tentative results. We expect to solidify and refine the linear steady-state theory mentioned earlier and to come to firm conclusions as we go along.

Finally, some preliminary calculations, based on assumed values of cornering and camber stiffness, indicate that the basic steer of both the lightest (the Honda 1255) and the heaviest (the HD Electraglide) machines in this program is oversteer. That is the $-^{h}o/C_{o}$ term in (4) is negative in both cases. This is due simply to the relatively far aft c.g. locations. However, when the $kC_{\alpha\phi}$ term is added, the Electraglide becomes about + 4°/g (u/s) while the Honda becomes more oversteer - i.e. - K $\cong$ -2.5°/g. The interesting thing is that the heavier machine understeer is of a magnitude that is not far from that of a typical small or medium car.