Technical Support Report

Effect of Driver Mass Tolerance on Motorcycle Emissions and Fuel Economy

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Notice

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Abstract

Motorcycle emissions and fuel economy were measured as driver mass was varied. Compared to the specified driver mass (80 kg), significant differences in emissions and fuel economy were first observed when the mass was varied ± 10 kg from the specified mass.

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Introduction

In developing the motorcycle regulations, two factors were considered when the driver mass tolerance was specified for emission testing. First, by specifying a restrictive tolerance, too many potential test drivers might be excluded. But, by specifying a broad tolerance, wide variations in emissions results were considered possible. Therefore, to accommodate both of these factors, the tolerance was specified as ± 10 kg.

To determine the appropriateness of this tolerance prior to final rule making, a test program was conducted to measure emissions and fuel economy at various driver masses. The test vehicle used was a Honda CB360 which represents a typical middle weight, four stroke motorcycle.

Summary and Conclusions

Based on the results of these tests the tolerance of ± 10 kg is an appropriate driver mass tolerance for emission testing.

Trends* of increasing HC, CO, and CO_2 and decreasing fuel economy were observed as driver mass was increased from about 60 to 120 kg. Though these emissions, fuel economy, and bag 1 NO_x correlated well with driver mass, bag 2 NO_x emissions were very low in concentration and difficult to accurately measure, and did not correlate well, while composite NO_x just missed correlating.

Discussion

A. Test Objective

The objective of this testing program was to determine the appropriateness with respect to emissions of the driver mass tolerance specified in §86.529(c)(1) of the motorcycle regulations.

To accomplish this emissions' measurements were made on a Honda CB 360 while driven over the Urban Dynamometer Driving Schedule. The test procedure with exceptions noted below were in accordance with the Federal Test Procedure. Nominal driver masses of 60, 70, 80, 90, 100, and 120 kg were tested where 80 kg is the specified nominal driver mass setting. To eliminate variations due to different drivers, such as in expertise, capability, and degree of training, the same driver was used throughout the testing sequence. Additional mass was centered directly underneath the driver to attain the higher mass settings. To obtain repeatable results and minimize test time, only hot start bag 1 and 2 tests were conducted. This was repeated three times at each driver mass setting.

* A significance level of .05 was used in these determinations. This same significance level is implicit in all subsequent references to trend and differences throughout this report.

B. Effect of Driver Mass

Figure 1 shows the results of this study plotted against nominal driver mass. These plots are not sufficient to reveal with confidence the relationship between emissions and driver mass.

To determine the relationship between emissions (and fuel economy) and driver mass, a linear regression analysis was performed. Using the mean emissions and fuel economy results at each driver mass, the regression equation has the form:

$$\text{Emissions} = a_o + a_1(\text{Driver Mass})$$

where a_o is the y-intercept and a_1 is the slope of the regression line.

Table 1 presents the effects on emissions and fuel economy of varying driver mass. Only those data displaying sufficient correlation are presented. Table 2 presents actual correlation coefficients which should be considered when interpreting these results. HC, CO, and CO_2 increased while fuel economy decreased with increasing driver mass and displayed good correlation. NO_x did not quite show sufficient correlation on a composite basis. (Bag 1 results correlated well, however, bag 2 results did not. This may have been due to the difficulty in measuring the low bag 2 concentrations of NO_x.)

After determining the relationships between emissions and driver mass, it was necessary to determine the extent to which driver mass could be varied from the specified driver mass before significant differences in emissions would be observed. To do this, an analysis of variance of emission results was performed. This is described by the following:

$$\frac{\bar{x}_{80} - \bar{x}_{DM}}{s\left(\frac{1}{n_{80}} + \frac{1}{n_{DM}}\right)}$$ is distributed as a t-statistic where:

$\bar{x}_{80}$ is the mean emissions at a driver mass of 80 kg

$\bar{x}_{DM}$ is the mean emissions at the driver mass to be compared

s is the pooled standard deviation and is equal to:

$$\sqrt{\frac{s_{80}^2(n_{80}-1) + s_{DM}^2(n_{DM}-1)}{n_{80} + n_{DM} - 2}}$$

n_{80}, n_{DM} are the number of test points at each driver mass, respectively

Using tables with the percentage points of the t-distribution, the level of significance of the comparison can be determined. Differences in emissions were considered significant at a significance level of about .05 or below.

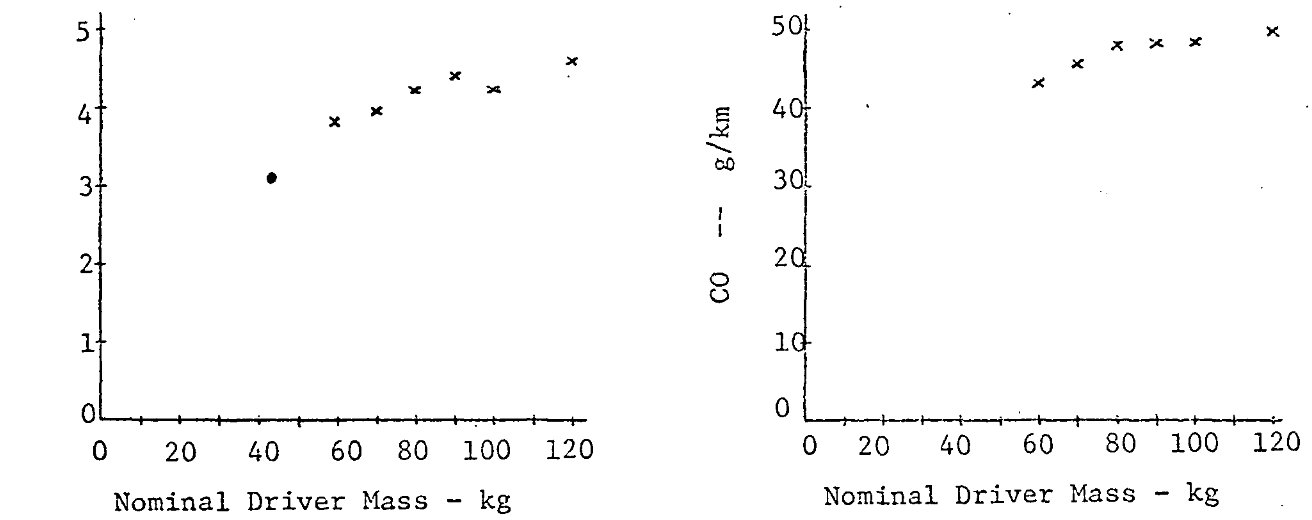

Figure 1

Effects of Driver Mass on

Motorcycle Emissions

and Fuel Economy

- Composite emissions from Bag 1 & 2 hot start tests.
- Test vehicle - Honda CB36C

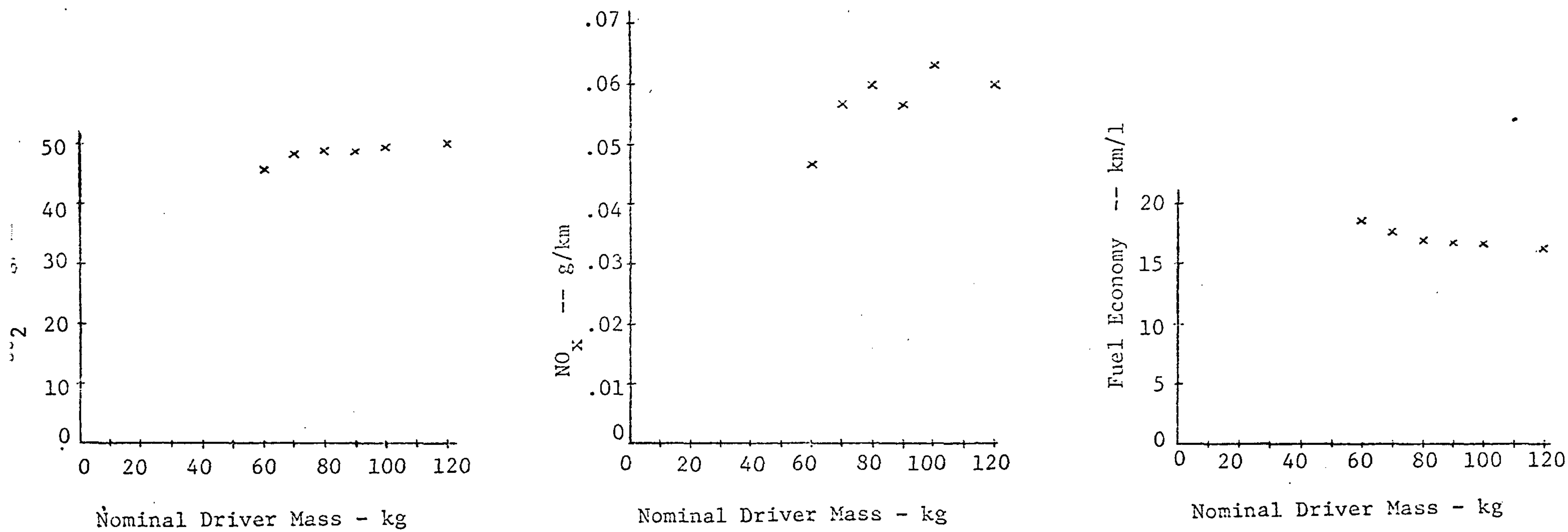

TABLE 1

Comparison Between Predicted Values Using Regression Equation and Actual Mean Emissions

	HC, g/km				CO, g/km				CO_2, g/km				NO_x, g/km	FUEL ECONOMY g/litre			
Nominal Driver Mass, kg	Regr. Eqn. Pred.	% Dif. from 80 kg	Actual Test Mean	% Dif. from 80 kg	Regr. Eqn. Pred.	% Dif. from 80 kg	Actual Test Mean	% Dif. from 80 kg	Regr. Eqn. Pred.	% Dif. from 80 kg.	Actual Test Mean	% Dif. from 80 kg		Regr. Eqn. Pred.	% Dif. from 80 kg	Actual Test Mean	% Dif. from 80 kg
60	3.88	-6.5	3.81	-10.1	44.6	-4.3	43.3	-9.8	46.9	-2.4	45.8	-6.3	(1)	18.1	+3.8	18.6	+9.4
70	4.02	-3.1	3.95	-6.8	45.7	-2.0	45.9	-4.4	47.6	-1.1	48.3	-1.2		17.8	+1.8	17.6	+3.5
80	4.15	---	4.24	---	46.6	---	48.0	---	48.1	---	48.9	---		17.5	---	17.0	---
90	4.29	+3.5	4.41	+4.0	47.6	+2.2	48.3	+0.6	48.8	+1.3	48.7	-0.4		17.1	-2.0	16.9	-0.6
100	4.42	+6.6	4.23	-0.2	48.6	+4.3	48.4	+0.8	49.3	+2.5	49.4	+1.0		16.8	-3.8	16.9	-0.6
120	4.69	+13.1	4.61	+8.7	50.6	+8.6	49.9	+4.0	50.5	+5.0	50.1	+2.5		16.1	-7.6	16.4	-3.5

(1) Insufficient correlation at a 95% confidence level to allow prediction.

TABLE 2

Driver Mass Regression Statistics

		HC	CO	CO_2	NO_x	Fuel Economy
Bag 1	r	.9263	.9328	.8886	.8191	-.9194
	r req'd for 95% conf. level	$\pm$ .8114	$\pm$ .8114	$\pm$ .8114	$\pm$.8114	$\pm$ .8114
	Signif. @ 95%?	yes	yes	yes	yes	yes
Bag 2	r	.8890	.8797	.8525	.6822	-.9169
	r req'd for 95% conf. level	$\pm$ .8114	$\pm$ .8114	$\pm$ .8114	$\pm$ .8114	$\pm$ .8114
	signif. @ 95%?	yes	yes	yes	no	yes
Composite	r	.9194	.9102	.8755	.7636	-.9036
	r req'd for 95% conf. level	$\pm$ .8114	$\pm$ .8114	$\pm$ .8114	$\pm$ .8114	$\pm$ .8114
	Signif. @ 95%?	yes	yes	yes	no	yes

Hypothesis Tests of the Slope of the Regression Lines

(H_o: slope = 0)

		H C	C O	C O_2	N O_x	Fuel Economy
Bag 1	slope	.0119	.1000	.0565	2.46×10^{-4}	-3.53×10^{-2}
	t-test signif. level	.0079	.0066	.0179	.0461	.0095
	reject H_o: slope = 0?	yes	yes	yes	yes	yes
Bag 2	slope	.0136	.0139	.0652	1.49×10^{-4}	-2.52×10^{-2}
	t-test signif. level	.0178	.0208	.0310	.1354	.0101
	reject H_o: slope = 0?	yes	yes	yes	no	yes
Composite	slope	.0128	.1021	.0612	1.89×10^{-4}	-3.40×10^{-2}
	t-test signif. level	.0095	.0117	.0223	.0772	.0135
	reject H_o: slope = 0?	yes	yes	yes	no	yes

Table 3 presents significance levels for comparisons of all driver masses. In figure 2 the shaded areas show where significant differences are first observed as driver mass is allowed to vary from the specified mass of 80 kg. For HC these differences occur almost exactly at $\pm$ 10 kg. For CO, CO_2, and fuel economy differences are first observed as shown in Figure 2, however a review of the significance levels in Table 3

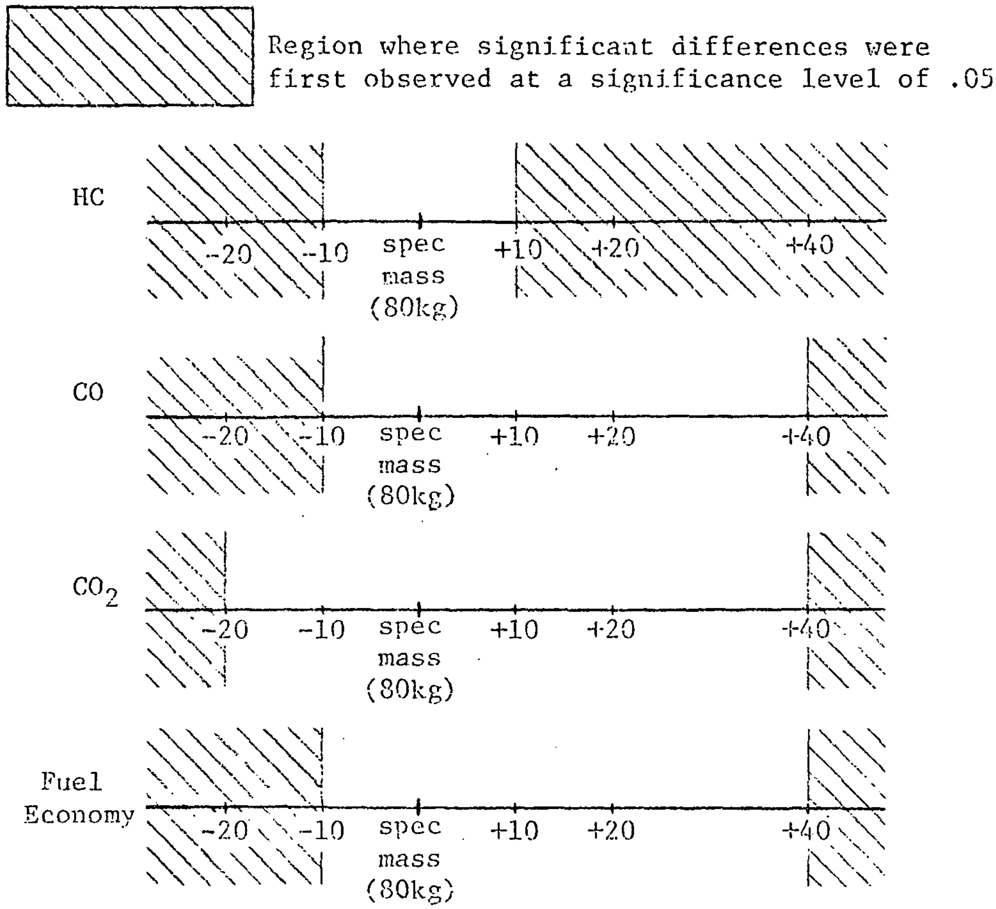

Figure 2

indicates that differences reach significance somewhat before the shaded areas indicate. No data were taken to show exactly where these differences become significant.

C. Physical Interpretation of the Effect of Driver Mass

For passenger car tires, it has been fairly well established[1,2] that as vertical load increases (decreases) the rolling resistance of bias ply tires also increases (decreases). Although this has not been shown to be true specifically for motorcycle tires, these tires are also of the bias ply type and it seems reasonable that they would behave in a

TABLE 3

Significance Levels -- T-test of Mean Emission at Various Driver Masses

HC Bag 1

	59.0	69.3	78.4	88.7	98.1
69.3	.0337	---			
78.4	.0002	.0225	---		
88.7	.0002	.0029	.0116	---	
98.1	.0003	.0093	.1342	.0664	---
117.5	.0000	.0008	.0013	.0842	.0056

HC Bag 2

	59.0	69.3	78.4	88.7	98.1
69.3	.6581	---			
78.4	.1131	.0672	---		
88.7	.0541	.0164	.2532	---	
98.1	.1864	.1366	.3585	.0353	---
117.5	.0206	.0060	.0294	.0410	.0086

HC Composite

	59.0	69.3	78.4	88.7	98.1
69.3	.3630	---			
78.4	.0254	.0476	---		
88.7	.0057	.0063	.0600	---	
98.1	.0218	.0384	.8588	.0163	---
117.5	.0026	.0026	.0097	.0306	.0040

CO Bag 1

	59.0	69.3	78.4	88.7	98.1
69.3	.0158	---			
78.4	.0003	.0007	---		
88.7	.0002	.0005	.0061	---	
98.1	.0009	.0059	.0805	.9442	---
117.5	.0001	.0003	.0011	.0161	.0690

CO Bag 2

	59.0	69.3	78.4	88.7	98.1
69.3	.0971	---			
78.4	.0113	.0009	---		
88.7	.0161	.0033	.2203	---	
98.1	.0130	.0006	.2666	.4979	---
117.5	.0056	.0006	.0248	.0130	.0096

CO Composite

	59.0	69.3	78.4	88.7	98.1
69.3	.0067	---			
78.4	.0007	.0001	---		
88.7	.0007	.0004	.3310	---	
98.1	.0007	.0006	.2369	.7116	---
117.5	.0002	.0000	.0005	.0027	.0064

CO_2 Bag 1

	59.0	69.3	78.4	88.7	98.1
69.3	.1060	---			
78.4	.0416	.4905	---		
88.7	.0319	.3509	.6221	---	
98.1	.0364	.3770	.6854	.9207	---
117.5	.0150	.0704	.0643	.0635	.1022

CO_2 Bag 2

	59.0	69.3	78.4	88.7	98.1
69.3	.0204	---			
78.4	.0198	.3752	---		
88.7	.0209	.7058	.5634	---	
98.1	.0052	.0216	.2833	.0648	---
117.5	.0067	.0413	.2224	.0769	.6126

CO_2 Composite

	59.0	69.3	78.4	88.7	98.1
69.3	.0224	---			
78.4	.0064	.2852	---		
88.7	.0085	.4483	.6247	---	
98.1	.0046	.1016	.2231	.1489	---
117.5	.0022	.0219	.0215	.0182	.1282

NO_x Bag 1

	59.0	69.3	78.4	88.7	98.1
69.3	.0132	---			
78.4	.0076	.1024	---		
88.7	.0092	.2508	.2302	---	
98.1	.0181	.1971	.4199	.2670	---
117.5	.0052	.0335	.1365	.0495	.9378

NO_x Bag 2

	59.0	69.3	78.4	88.7	98.1
69.3	.1246	---			
78.4	.1346	.3739	---		
88.7	.1959	.4918	.5946	---	
98.1	.0673	.1929	.1688	.1552	---
117.5	.1071	.3739	.1583	.3349	.2511

NO_x Composite

	59.0	69.3	78.4	88.7	98.1
69.3	.0426	---			
78.4	.0325	.2879	---		
88.7	.0495	.7676	.2746	---	
98.1	.0259	.1462	.2174	.1355	---
117.5	.0206	.0668	.1550	.0697	.5593

similar manner. Thus, the increased vertical load increases the power required to move the vehicle at a given speed. This requires greater throttle openings thereby increasing the mass flow of air-fuel mixture into the engine. Since the air-fuel ratio did not change significantly*, the greater throttle opening has the effect of increasing the mass of emissions and fuel consumption which was substantiated by the data in this study.

D. Applicability to Other Motorcycles

The results of this study should be applicable to other motorcycles on a general basis. To overcome added load, it is necessary for all motorcycles to increase throttle opening which will increase their mass emissions and fuel consumption. This effect may be more dramatic for smaller motorcycles and somewhat less noticable for larger ones, however, the aggregate effect would be expected to be similar to that shown by this study.

E. Recommendations

These tests revealed that emissions and fuel economy become significantly different as driver mass deviates by about 10 kg from the specified value of 80 kg. Because a restrictive tolerance would exclude many potential drivers, and a broad tolerance will significantly affect emissions and fuel economy results, it is recommended that the driver mass tolerance be $\pm$ 10 kg.

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* These results are not shown because of their approximate nature.

References

1. Willet, P.R., "Hysteretic Losses in Rolling Tires," Rubber, Chemistry, and Technology, Vol. 46, No. 2, pg 425-441 (1973).

2. Schuring, D.J., "Rolling Resistance of Tires Measured Under Transient and Equilibrium Conditions on Calspan's Tire Research Facility," Dept. of Transportation Report No. DOT-TSC-OST-76-9, pg 69-71 (March 1976)