Informal document No. **26**
(53 GRRF, 3-7 February 2003,
agenda item 2.)

IMMA INTERNATIONAL MOTORCYCLE MANUFACTURERS ASSOCIATION

GLOBAL HARMONISATION OF PTW AND 3-WHEELER BRAKING

REVIEW OF IMMA SEVERITY TEST WORK.

INTRODUCTION

The harmonisation of motorcycle braking regulations is a priority item under the 1998 Global Agreement for establishing Technical Regulations for Wheeled Vehicles. IMMA therefore took the initiative and in 1999 set up a task force to develop this project.

Initially, the following general points were agreed with GRRF :
- With the exception of some parts of the Japanese Safety Standard 12-61, current regulations world-wide are derivatives of either FMVSS 122 or ECE R78
- The new Global Technical Regulation would be based on the most severe requirements from FMVSS 122 and ECE R78
- The GTR would not include any performance reductions over current regulations

Except for the high speed test, the Japan Safety Standard 12 – 61 is similar to ECE and when comparing FMVSS with ECE, it should be noted that the Japan SS was also included in the analysis.

It was therefore decided that a severity rating would have to be applied to the key test procedures. After comparing the FMVSS and ECE regulations, it became clear that there were four significant test items that should be analysed in detail to decide which should be included in the GTR. i.e. the test with the most severe requirements.
These were :
1. Dry Stop Tests
2. Heat Fade Test
3. Wet Brake Test
4. High Speed Test

This paper reports on the findings of the vehicle severity testing that was carried out by IMMA members on the above four test procedures.

SEVERITY TESTS

General notes:
The following tests were carried out by skilled test riders, on test surfaces that were level and had a high coefficient of friction.
The test motorcycles were in good condition, fully equipped with relevant test safety and data monitoring systems, and the brakes were renewed and reburnished as appropriate between sets of tests.
The test motorcycles were all in standard OE condition and had conventional brake systems i.e. independent front and rear wheel braking.
The front control-force measuring points for each test complied with each regulation:

- FMVSS: 1.2 inches from the end of the brake lever grip
- ECE/Japan; 5 cm from end of the brake lever

Average control forces were used for both FMVSS and ECE tests.

1.0 Dry Stop Tests

In order to compare the severity of FMVSS v ECE tests, the following assessments were made on the same test vehicle:
- Measure the brake control force required to obtain the prescribed legislative deceleration.
- Using the brake control forces found in the above test, record the resultant vehicle average deceleration.

These tests were performed on a range of motorcycles of varying sizes.

1.1 Test Method

1.1.1 Vehicles
6 different motorcycle models were used as follows :
Large capacity : Kawasaki (Cruiser), 1500 cc.; Yamaha(Sport),1300 cc.;
Suzuki(Sport) 750 cc.
Small capacity : Yamaha (Dual purpose), 225 cc.; Suzuki (STD), 125cc;
Kawasaki(Cruiser) 125 cc.

1.1.2 Procedures
Based on FMVSS and ECE procedures - See Annex 1 for summaries

1.1.2.1 FMVSS
- For each test motorcycle, in the unladen condition, carry out stops from 30 mph (48 km/h) with simultaneous application of front and rear brake control.
- Measure the brake control forces that achieve the prescribed deceleration of 6.87 m/s^2

1.1.2.2 ECE

- For each test motorcycle, in the **laden** condition, carry out stops from 60 km/h with **separate** application of front and rear brake control.
- Measure the brake control forces that achieve the prescribed decelerations :
  Front = 4.4 m/s^2. Rear = 2.9 m/s^2.
- Carry out further laden stops from 60 km/h in accordance with the ECE procedure but using the brake control forces that were obtained during the FMVSS test 1.1.2.1. Stops to be with :

a. Both brakes together
b. Front only braking
c. Rear only braking

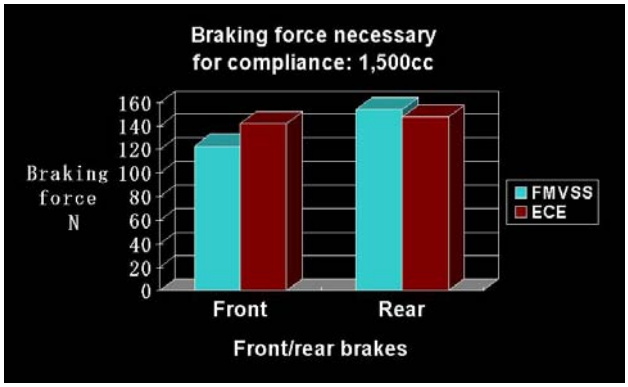
1.2 Results

1.2.1 Brake Control Force (N) needed to achieve the prescribed deceleration

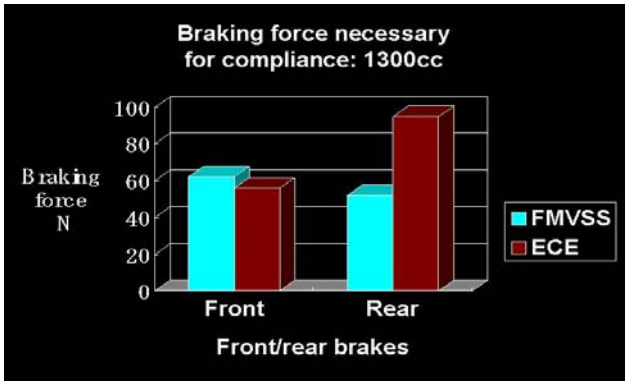
	FRONT		REAR	
MODEL	FMVSS	ECE	FMVSS	ECE
1500 cc	124	142	153*	149
1300 cc	62*	56	53	95
750 cc	40	45	75	185
225 cc	98*	88	78	150
125 cc	92	108	97	122
125 cc	70	75	90	255

See the following graphs 1a, 1b, 1c, 1d, 1e, 1f.

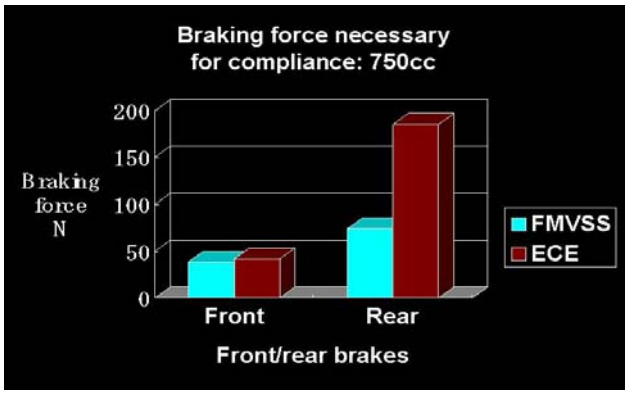
1a



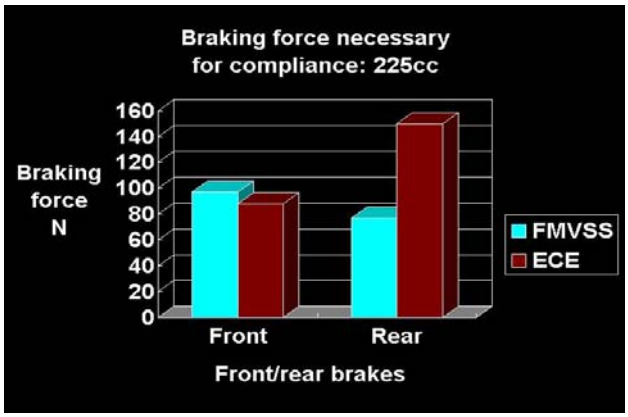
1b


Braking force necessary
for compliance: 1300cc
Braking force N
100
80
60
40
20
0
Front
Rear
Front/rear brakes
FMVSS
ECE

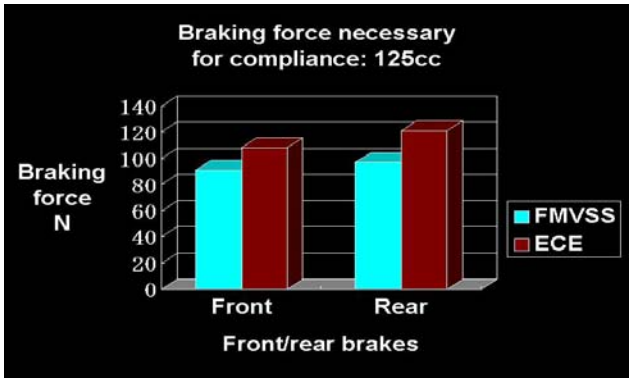
1c


Braking force necessary
for compliance: 750cc
Braking force N
200
150
100
50
0
Front
Rear
Front/rear brakes
FMVSS
ECE

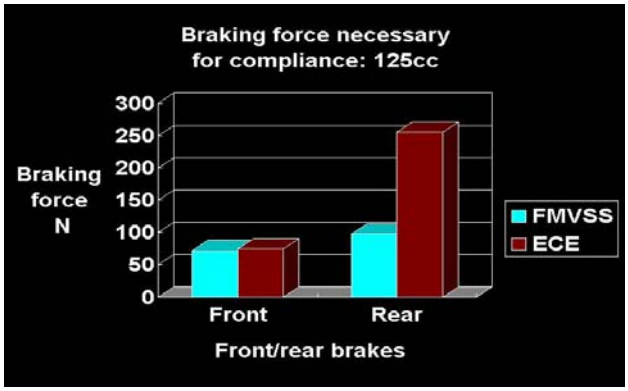
1d


Braking force necessary
for compliance: 225cc
Braking force N
160
140
120
100
80
60
40
20
0
Front
Rear
Front/rear brakes
FMVSS
ECE

1e


Braking force necessary
for compliance: 125cc
Braking
force
N
140
120
100
80
60
40
20
0
Front
Rear
Front/rear brakes
FMVSS
ECE

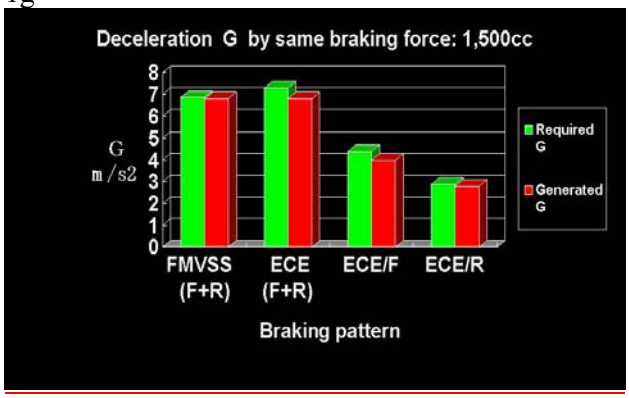
1f


Braking force necessary
for compliance: 125cc
Braking
force
N
300
250
200
150
100
50
0
Front
Rear
Front/rear brakes
FMVSS
ECE

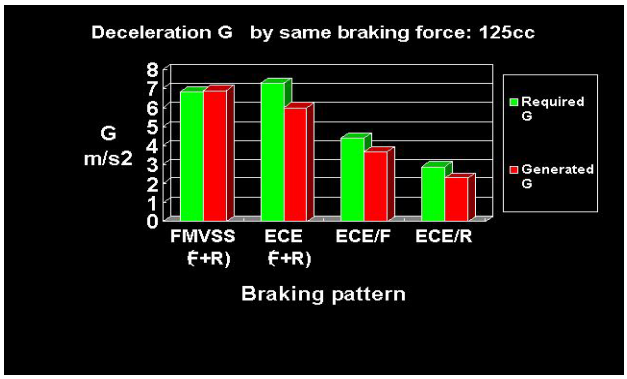
1.2.2 Deceleration Generated (m/s^2) when using the ECE procedure with the FMVSS brake control forces (graphs 1g, 1h)

MODEL	FRONT + REAR		FRONT		REAR	
	Achieved Decel	ECE requirement	Achieved Decel	ECE requirement	Achieved Decel	ECE requirement
1500 cc	6.8	7.3	4	4.4	2.8	2.9
125 cc	6	7.3	3.7	4.4	2.3	2.9

1g



1h



1.3 Comments

With the exception of the three results marked with an *, in the 24 tests a higher brake control force was required to meet the ECE requirement than that in the FMVSS.
Of these three results, the ECE result was up to 10 % lower than that for the FMVSS.

The second test shows that the motorcycle with minimum permissible braking performance for FMVSS cannot comply with the ECE requirement.

The above two sets of results show that overall, the ECE procedure is more severe than FMVSS.

2.0 Heat Fade Test

For comparison purposes, the same test motorcycle performed heat fade tests to both the FMVSS and the ECE procedures. The baseline and recovery parts of the procedures were not included. The level of severity was established by recording the brake temperatures throughout both tests. The higher the temperature, the more severe the test is.

2.1 Test Method

2.1.1 Vehicle
A 600 cc. Honda (Sport) motorcycle with a mass of 200kg (unladen) equipped with front and rear disc brakes.

2.1.2 Procedures
Based on FMVSS and ECE procedures – See Annex 1 for summaries

2.1.2.1 FMVSS
- With the motorcycle in the unladen condition and the engine disconnected, carry out 10 repeated stops from 60 mph (96 km/h) at a deceleration of 15 ft/s^2 (4.6 m/s^2) with simultaneous application of front and rear brake.
- 0.4 mile (640 m.) interval between each stop.
- Record brake pad temperatures throughout the test.

2.1.1.2 ECE
- Front Brake : In the **laden** condition with the engine connected from the initial speed to 50% of the initial speed and disconnected from 50% of the initial speed to Zero, carry out 10 repeated stops from 100 km/h using front brake only application at a deceleration of 3 m/s^2.
- Rear Brake : In the **laden** condition with the engine connected from the initial speed to 50% of the initial speed and disconnected from 50% of the initial speed to Zero, carry out 10 repeated stops from 80 km/h using rear brake only application at a deceleration of 3 m/s^2.
- 1000 m. interval between each stop.
- Record brake pad temperature throughout the test.

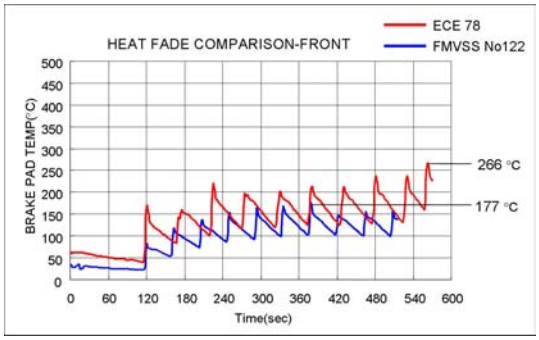
2.2 Results

Maximum Brake Pad Temperature recorded during Heat Fade test stops

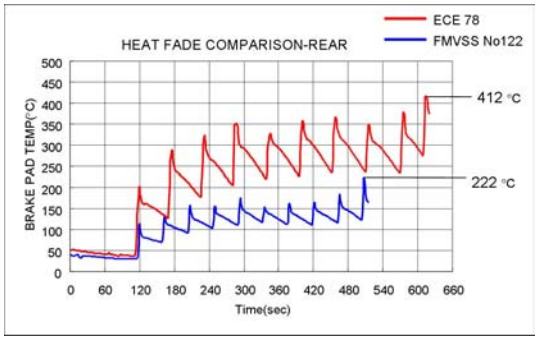
STOP NO.	FRONT PAD TEMP °C		REAR PAD TEMP °C	
	FMVSS	ECE	FMVSS	ECE
1	80	165	115	200
2	120	160	130	280
3	130	220	160	325
4	150	200	155	350
5	170	205	175	325
6	165	215	155	360
7	177 max	215	165	370
8	150	240	165	350
9	155	240	180	380
10	160	266 max	222 max	412 max

See the graphs 2a, 2b

2a



2b



2.3 Comments

The above chart shows that the ECE test generates much higher brake temperatures than FMVSS. The higher temperature in the ECE test is due to the higher kinetic energy absorption during the heat-fade braking procedure. Therefore, the ECE heat fade test is significantly more severe than the FMVSS version.

3.0 Wet Brake Test

The same test motorcycle was used to perform both FMVSS and ECE procedures so that a valid comparison of the results could be made. For FMVSS, a detailed analysis was made of the wet v dry brake control forces during the 5 stop recovery schedule that is carried out after total brake immersion. These results were then compared with the ECE result where the brake is wetted by a continuous spray on the disc

3.1 Test Method

3.1.1 Vehicle

A large motorcycle (200 kg. Mass) with front and rear disc brakes fitted with sintered pad material.

3.1.2 Procedures

Based on FMVSS and ECE procedures – See Annex 1 for summaries.

3.1.2.1 FMVSS –

- Carry out dry, front-brake-only stops from 30 mph (48 km/h) at 10 – 11 ft/s^2.(3.05 – 3.35 m/s^2) with the vehicle unladen and determine the maximum brake control force used.

- Completely immerse the front brake in water for 2 minutes with the brake released.
- Immediately after removing the vehicle from the water, carry out 5 stops from 30 mph at 10 – 11 ft/s^2. Measure the brake control force during each stop. The result of the 5th stop is used for regulatory purposes.
- Max interval between each stop = 1 mile.

3.1.2.2 ECE –

- With the motorcycle in the **laden** condition, carry out a front-brake-only Dry Stop test from 60 km/h to find the control force that gives a deceleration of 2.5 m/s^2.
- Repeat the above test (with the control force that gives a deceleration of 2.5 m/s^2) but with water being sprayed onto the disc at 15 litre/hr.
- Measure the vehicle deceleration in the period 0.5 – 1.0 seconds after brake application.

3.2 Results

3.2.1 FMVSS

DRY BRAKE	Baseline dry brake control force	39.5 N
WET BRAKE Dry control force ÷ Wet control force	Stop 1	81.5 %
	Stop 2	88.8 %
	Stop 3	95.2 %
	Stop 4	97.6 %
	Stop 5	98.3 %

3.2.2 ECE

Baseline Dry Brake Control Force = 34 N.

With a front brake control force that gave a deceleration of 2.5 m/s^2 :
Wet brake deceleration. ÷ Dry brake deceleration. = 85.6 %

3.3 Comments

Although the FMVSS and ECE procedures use different philosophies, it is possible to find an approximate link for comparison purposes from the above tables, as follows:
The ECE test gave a wet brake efficiency result of 85.6 % under conditions of continuous wetting.
By using the brake control force as an index of the brake's recovered efficiency, in the FMVSS test, 88,8% of the initial efficiency had been recovered after 2 stops whilst after the 5th stop, the figure was 98.3 %, i.e. a virtually dry brake.
Therefore, as the motorcycle and brakes were the same for each test, the ECE test was more stringent as it produced a continuously lower wet brake efficiency.

4.0 High Speed Test

The purpose of this dry brake test is to evaluate the ability of the brake system to stop the motorcycle safely from high speed. In contrast to the previous tests, the High Speed Test compared FMVSS to the Japan Safety Standard. This was because the ECE does not include a target deceleration value whilst the others do.
Also, Japan's SS and ECE include a stability check during braking that is not part of the FMVSS procedure.
The comparison was in 2 parts :

a. A vehicle test comparing the brake control forces.
b. A theoretical exercise comparing the kinetic energy absorbed for the 2 procedures.

4.1 Brake Control Force Comparison

Four test motorcycles were each used to carry out both FMVSS and Japan's SS procedures. The relative level of severity was obtained by comparing the brake control forces applied to meet the target vehicle deceleration requirement. Higher force = more severe.

4.1.1 Test Method

4.1.1.1 Vehicles
Motorcycles – a Honda, Suzuki and Yamaha 1000 cc and a Kawasaki 900cc Sport

4.1.1.2 Procedures
Based on FMVSS and Japan's SS procedures – See Annex 1 for summaries

FMVSS
- With the motorcycles in the unladen condition, carry out stops from 192 km/h with simultaneous application of both front and rear brake to give a deceleration of 5.4 m/s^2. Engine disconnected.
- Measure the brake control forces.

JAPAN SS
- With the motorcycles in the unladen condition, carry out stops from 160 km/h with simultaneous application of front and rear brakes to give a deceleration of 5.8 m/s2. Engine **connected.**
- Measure the brake control forces.
- Record vehicle behaviour

4.2 Theoretical Comparison of Kinetic Energy

Consider the formula for Kinetic Energy : ½ mv^2, where m = mass and v = velocity

When the same vehicle is used for comparison, velocity is the only variable. The velocities from FMVSS and Japan's SS are compared in the Results below.

4.3 Results

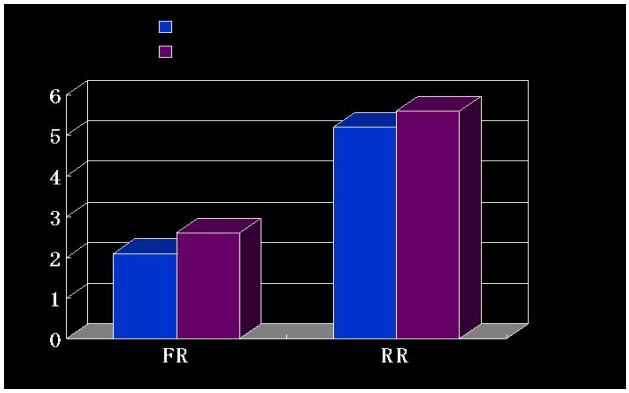
4.3.1 Vehicle Test Results

Brake Control forces to meet required deceleration (N)

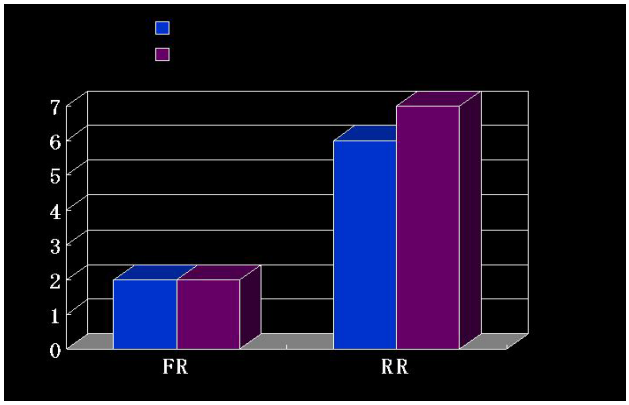
	FRONT CONTROL FORCE		REAR CONTROL FORCE	
Motorcycle	FMVSS (blue)	JAPAN SS (red)	FMVSS (blue)	JAPAN SS (red)
A – 1000 cc	2.2	2.6	5.2	5.6
B – 1000 cc	2	2	6	7
C – 900 cc	3.3	3.5	6.8	6.9
D – 1000 cc	2.6	3.5	5.3	6.3

See the following graphs 4a, 4b, 4c, 4d.

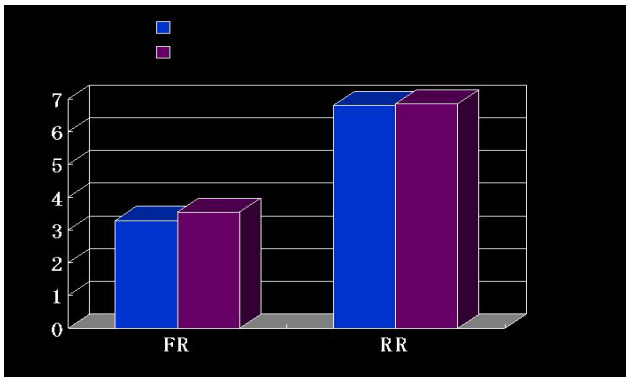
Average Control Forces (in Kgf) for model A (1000cc) – Braking Necessary for Compliance (4a)



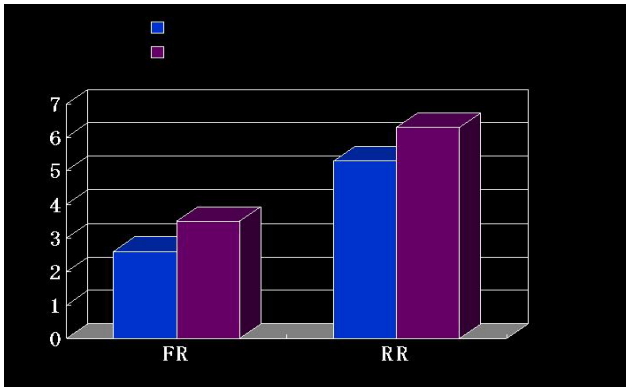
Average Control Forces (in Kgf) for model B (1000cc) – Braking Necessary for Compliance (4b)



Average Control Forces (in Kgf) for model C (900cc) – Braking Necessary for Compliance (4c)



Average Control Forces (in Kgf) for model D (1000cc) – Braking Necessary for Compliance (4d)



4.3.2 Kinetic Energy Comparison

The initial test speed for FMVSS is 192 km/h (120 mph) but for Japan's SS it is 160km/h.

Therefore the Kinetic Energy is higher in the FMVSS test.

4.4 Comments

The brake control forces required to meet the required vehicle deceleration are, with one exception, significantly higher when using the Japan's SS procedure. This is due to the Japan's SS deceleration of 5.8 m/s^2 being higher than the FMVSS value of 5.4 and so this is a more severe test.

Due to its higher initial speed of 192 km/h, the FMVSS test develops more kinetic energy than the Japan's SS test and hence is the more severe test.

The Japan's SS includes a vehicle stability check which FMVSS does not. Therefore, the Japan's SS is the more severe test.

The remaining parameter is whether to use engine disconnected (FMVSS) or connected (Japan's SS). It is recommended that the test is with engine connected as it simulates the real life use conditions for a more realistic stability check.

CONCLUSIONS

The results from the severity rating of the four key test items were as follows:

1. Dry Stop Tests – Overall, the ECE procedure was shown to be more severe than FMVSS.

2. Heat Fade Test – The ECE test was much more severe, largely due to the higher kinetic energy absorption.

3. Wet Brake Test – Even though different test philosophies were used, e.g. FMVSS is based on total immersion, ECE is based on continuous wetting, the ECE test was more severe and more representative of typical use.

4. High Speed Test – The Japan's SS test was more severe when brake control forces were being compared but FMVSS was more severe if the kinetic energies were analysed. The Japan's SS is more complete in that a vehicle stability check is included.

It is therefore proposed that the ECE test procedures for Dry Stop, Heat Fade, and Wet Brake are incorporated into the GTR.

For the high speed test, the Japan SS procedure should be used but with an increased initial speed to align with the FMVSS requirement.

The proposed GTR will thus give significant enhancement to the current FMVSS regulation for all test procedures and an improvement in the high speed test procedure for Europe and Japan.

Dr NM Rogers
03/02/06

ANNEX 1

SUMMARY CHART COMPARING FMVSS 122, ECE R78 AND JAPAN SAFETY STANDARD No. 12 + 61.

ITEM	FMVSS 122	ECE REG 78	JAPAN SS 12 – 61
Dry stop tests -High speed test	S5.3 & S7.5 Second Effectiveness– Stops using both brakes, engine disconnected, and vehicle unladen with following requirements: 30 mph – 43 ft → a_{30} = 6.87 m/s^2 60 mph – 185 ft → a_{60} = 6..38 m/s^2 80 mph – 345 ft → a_{80} = 6.07 m/s^2	Annex 3 – 2.1.1 – 2.2.2.2 Single braking device or CBS tests with the vehicle generally laden from 60 km/h. (L_1 + L_2 at 40 km/h) If single brake cannot reach prescribed decel (L_3 = 4.4 m/s^2 Front , 2.9 m/s^2 Rear) , use vehicle laden with both braking devices together to meet (L^3 = 5.8 m/s^2)	Similar to ECE but no requirement for using vehicle laden with both braking devices together.
	As above but from a speed of : 1 mile full accel. . Max speed = 120 mph (192 km/h) Stopping distance = 861 ft. max (equivalent to 5.4 m/s^2)	Annex 3 – 1.4.3 L_3,L_4 & L_5 vehicles unladen using both brakes with engine connected from a speed of 160 km/h or 0.8 v max whichever is less. Max practical performance and vehicle behaviour shall be recorded. Note : Test also performed at lower speeds – down to 30% v max.	Similar to ECE but with min. mfdd = 5.8 m/s^2
Fade and recovery	S5.4 - Not applicable when the max speed attainable in 1 mile < 30 mph *	Annex 3 – 1.6.1.1 L_3,L_4, and L_5 in laden condition. If CBS, only CBS to be fade tested	Same as ECE
Fade baseline check	S5.4.1 & S7.6.1 – Using both brakes, 3 stops from 30 mph at 10 to 11 f/s^2 (= 3.05 to 3.35 m/s^2) Compute the average of the max brake pedal and max brake lever forces → F_{ave} (pedal and lever forces to be within specified limits)	Annex 3 – 1.6.1.2 1 Dry stop test (Service braking) – as in item 13 above.	
Fade test	S5.4.2 & S7.6.2– Using both brakes, and vehicle unladen, 10 stops from 60 mph at > 15 f/s^2 (= 4.57 m/s^2) with 0.4 mile between each service brake application. After 10th stop, drive 1 mile at 30 mph and conduct recovery test.	Annex 3 – 1.6.1.2.2 - 10 stops with vehicle laden. - Test each brake separately (if CBS, then only CBS) - Speeds – Front + CBS = 100 km/h Rear = 80 km/h - Braking interval = 1000 m - Suitable gear for 50% stop, engine disconnected for remainder. - Decel = 3 m/s^2 with constant force.	
Recovery test	S5.4.3 & S7.6.3- 5 stops from 30 mph at 10 to 11 f/s^2. Braking interval < 1 mile. 5th stop forces within +20 and –10 pounds of baseline F_{ave}	Annex 3 – 1.6.1.2.3 Repeat Fade Baseline Check ASAP or at least within 1 minute after completion of fade test. 1.6.3 – Decel = > 60% of baseline test	

ITEM	FMVSS 122	ECE REG 78	JAPAN SS 12 – 61
Wet braking	S5.7 – Tests with both brakes and unladen vehicle.	Annex 3 – 1.4.4 - Same vehicle/test conditions as Dry brake test (Item 13) - For vehicle categories L_1,L_2,L_3,L_4. - Exemption for conventional drum and fully enclosed disc brakes	Same as ECE
Baseline check	S5.7.1 - 3 stops from 30 mph at 10 to 11 f/s ^{2} . Compute the average of the max input forces to F_{ave}	Annex 3 – 2.5.2 - Carry out a Dry Brake test and measure the control force at 2.5 m/s^2	
Wet brake test	S5.7..2 - Completely immerse the rear brake and then the front brakes for 2 minutes with the brakes fully released. Followed by 5 stops from 30 mph at 10 to 11 f/s^2. Braking interval < 1 mile. For the 5 stops, lever/ pedal forces shall not exceed 55 lbs. For 5th stop forces shall be within + 20 and – 10 pounds of F_{ave}.	Annex 3 – 2.5 - With equipment continuously wetting the brakes at a flow rate of 15 l/h., Mfdd attained between 0.5 and 1 sec after brake application to be > 60% and <120% of mfdd for dry brakes performance ie. Base line check.	
Test conditions			
Vehicle weight	S6.1 Unloaded vehicle (including driver and instrumentation) plus 200 pounds	In general, vehicle is fully laden except : - High speed test(1.4.3) unladen. - CBS tests laden and unladen - ABS tests unladen Notes: 1. Fully laden = manufacturers max mass. unladen = rider and test equipment 2. Test with rider alone not required if calcs show that >2.5 m/s^2 is possible	In general, vehicle is fully laden except : - High speed test unladen - ABS test unladen - CBS test laden only Definitions : 1.Laden = "Loaded" From GVW to GVW + 65 kg. 2.Unladen = "Unloaded" From vehicle weight plus 55 kg to 100 kg.
Thermocouples	S6.9 – Brake temperature is measured by plug type thermocouples installed in the center of the most heavily loaded pad/shoe.	Annex 3 – 1.3.1.3 …temperature measured on the disc or on the outside of the drum …..	
Brake actuation force	S6.10 Hand lever force: > 2.3 lb → 10.4 N < 55 lb→ 249 N Foot pedal force: >5 lb → 22.7 N < 90 lb→ 408 N Point of application 1.2 inches (=3 cm) from end of grip.	Annex 3 – 1.2.4.2.4 Hand control: < 200N Foot control: < 350 N (L_1,L_2,L_3,L_4) <500 N (L_5) Point of application 5 cm from end of lever.	Same as ECE