FSAE TIRE TEST CONSORTIUM -- ROUND 4

From: Edward M. Kasprzak, FSAE TTC Co-Director
To: FSAE TTC members
Date: 14 November 2009

This document describes the data and files provided for Round 4 of testing, provides a guide to the tests and acknowledges the people and organizations who have made this effort possible.

New for this round of testing is electronic distribution of the data from the secure FSAE TTC server at: http://sae.wsu.edu/ttc/ DVDs will not be shipped, except for new FSAE TTC members.

Users are reminded of the terms of their membership as stated on the FSAE TTC website (www.millikenresearch.com/fsaettc.html) which states the following:

> Consortium members are free to use this data in the design and construction of their FSAE entries, other school projects and related academic activities. ***Any publication or presentation of the tire data must acknowledge Calspan and the FSAE TTC.*** Individuals and teams are prohibited from donating or selling the data to any other individual, group, team or university, or posting it on the internet. […] The data may not be used in any commercial application.

We note that, while two of the three Directors are employed at Milliken Research Associates, Inc. and the main webpage is hosted at MRA's web address, the FSAE TTC is a fully independent entity.

I. Acknowledgements

The FSAE Tire Test Consortium has been founded, organized and lead by three Co-Directors:

Dr. Edward M. Kasprzak, Milliken Research Associates, Inc. and University at Buffalo, SUNY
Dr. Bob Woods, University of Texas, Arlington
Doug Milliken, Milliken Research Associates, Inc.

Since Round 3, Brian Seater of Washington State University has contributed greatly to the FSAE TTC. He established and maintains the secure forum where students can openly discuss the tire data. He has also provided a means for electronic distribution of the tire data.

Denny Trimble (University of Washington) helped establish the FSAE TTC during his student days and has since moved-on.

The FSAE TTC has received support from the following people and organizations:

Doug Milliken—FSAE Judge and Vice President of Milliken Research Associates. Doug Milliken continues to independently oversee the FSAE TTC finances and has contributed considerable time and effort to the consortium—above and beyond the call of duty. He has also donated a model of the data (MRA Nondimensional Tire Model), which will be posted once it is complete.

Mike Stackpole—Stackpole Engineering Services. Mike Stackpole has donated a Pacejka ’96 model of the data, which will also be posted when it is complete.

The Goodyear Tire and Rubber Company once again donated tires and shipped them to Calspan at no cost to the FSAE TTC.

Hoosier Racing Tire once again donated tires and shipped them to Calspan at no cost to the FSAE TTC.

Michelin donated tires and shipped them to Calspan at no cost to the FSAE TTC.

Dunlop Motorsport, a new participant in Round 4, donated tires and shipped them to Calspan at no cost to the FSAE TTC.

Calspan Tire Research Facility (TIRF). Thanks to Dave Gentz, Joe Dunlop and everyone at Calspan for making another round of tire tests possible. Calspan continues to support the FSAE TTC and are always interested to hear of schools applying the data to their FSAE entries. This is the fourth time Calspan has provided the consortium a price break for the testing (again, they didn’t turn a profit on this project). Everyone worked just as hard on this project as they do with their corporate and professional racing customers, and the staff went out of their way to accommodate FSAE students who attended the test. The Calspan Tire Research Facility is a top-notch operation—display your Calspan decal with pride, and be sure to reference them and the FSAE TTC properly when using the data.

Calspan has also provided a cover letter with the delivery of the data. This is included in the distribution.

II. Guide to Round 4 of testing

1. Overview

The fourth round FSAE TTC tests was conducted in late October 2009. The amount of data collected in this round of testing far exceeds that collected in previous rounds.

Six different tires were tested, each on two different rim widths. The wheels used are the same as in Round 3–steel wheels purchased from Diamond Racing Wheels (Mini CC series). The tires tested in Round 4 are:

- Dunlop 175/505R13
- Goodyear 20.0x7.0-13 “D2696”
- Hoosier 20.5x6.0-13 R25B
- Hoosier 20.5x7.0-13 R25B
- Hoosier 20.0x7.5-13 R25B
- Michelin 16/53-13 “Radial X S6B”

Highlights of the Round 4 test plan include:

- Each tire/rim combination was put through a full matrix of load, inclination angle and pressure combinations. This differs from previous rounds where full data was only available at 12 psi.
- A “cold to hot” series of sweeps was added to each test to track the break-in of a new tire and watch performance change as tread temperature increased.
- A more agressive break-in and warmup procedure helps ensure that early test sweeps are at representative temperatures
- Certain operating conditions are repeated throughout the test for comparison. This includes a full repeat of the first pressure (12 psi) after the other test pressures were recorded.

This project has the Calspan TIRF project number “1320”. You will see this number throughout the raw data files. For example, a typical data file might be named “1320run7.dat”, which is Run 7 in the project.

The table on the next page relates run numbers to the tires tested in Round 4. For convenience, this is also included as a separate file, “RunGuide_Round4.pdf”.

FSAE TTC -- ROUND 4 RUN GUIDE

Run numbers correspond to the data files, such as "A1320run47.dat" for Run 47.

		Rim Width, in	Cornering Test (psi)				Drive/Brake/Combined Test (psi)			
			8	10	12	14	8	10	12	14
Dunlop	175/505R13	7	7	5	4*, 8, 154**	6	72y 146	70y 144	68wy, 69y, 73y 142w, 143, 147	71y 145
Dunlop	175/505R13	8	12x	10	9*, 13	11	78y 152	76y 150, 153	74wy, 75y, 79y 148w, 149	77y 151
Goodyear	20.0x7.0-13	7	17	15	14*, 18, 155**	16	96	94	92w, 93, 97	95
Goodyear	20.0x7.0-13	8	22x	20	19*, 23	21	102	100	98w, 99, 103	101
Michelin	16/53-13	7	27	25	24*, 28, 156**	26	84	82	80w, 81, 85	83
Michelin	16/53-13	8	32	30	29*, 33	31	90	88	86w, 87, 91	89
Hoosier	20.5x6.0-13	6	38	36	34*, 39	37	116	114	112w, 113, 117	115
Hoosier	20.5x6.0-13	7	43	41	40*, 44	42	110	106w, 107	108, 111	109
Hoosier	20.5x7.0-13	6	48	46	45*, 49	47	122	120	118w, 119, 123	121
Hoosier	20.5x7.0-13	7	53	51	50*, 54, 157**	52	128	126	124w, 125, 129	127
Hoosier	20.0x7.5-13	7	58x	56	55*, 59	57	134	132	130w, 131, 135	133
Hoosier	20.0x7.5-13	8	64x	62	61*, 65	63	140	138	136w, 137, 141	139

* indicates initial spring rates, cold-to-hot test and warm-up/conditioning cycles included with regular test sweeps

** indicates initial spring rates, cold-to-hot test and warm-up/conditioning cycles ONLY on a used tire (appx. 2-3 days since last use)

w indicates initial spring rates, cold-to-hot test and warm-up/conditioning cycles ONLY (same warmup as in cornering test)

x indicates the tire de-beaded. Test was not completed at this pressure. Partial data only.

y indicates original drive/brake/combined test procedure -- intensity of warmup/conditioning increased starting with run 80

2. Summary Tables

More information on each test can be found in the Excel spreadsheet "1320 Summary Tables.xls" provided by Calspan. This spreadsheet includes the following pages:

Cornering Schedule – expanded version of the run log
Drive/Brake Schedule – expanded version of the run log
Tire ID Schedule – list of tires, including compounds and other sidewall codes
Test Spring Rate and Cornering Stiffness –cornering stiffness, cornering stiffness coefficient, lateral force at zero slip angle and spring rates from the main data sweeps.
Pre- Post- Spring Rates – spring rates from the spring rate tests before and after the main data sweeps
Pyrometer Reading – list of carcass temperatures taken immediately after the end of each run

3. CorneringTest Plan

The data is separated into two distinct test plans: "Cornering" and "Drive/Brake". The cornering test was run with a free-rolling tire. Five loads, five inclination angles and four inflation pressures were recorded.

The start of the test includes a "cold to hot" series of eight slip angle sweeps at the same load. This helps bring the tire up to temperature and gives an indication of how a new tire changes as it breaks-in.

The initial pressure (12 psi) is retested as the final pressure. This is done to facilitate comparisons between a new and used tire, as well as between a somewhat cooler tire and one that has reached a nominal thermal equilibrium.

The cornering test plan outline with events in chronological order:

Speed: 25 mph for all tests
Note: Below, "SA1" means "sweep ± 12 degrees (–4 to +12 to –12 to +3) @ 4deg/sec"

Spring rate at 0 mph: 0, 2 and 4 IA @12 psi
Spring rate at 25 mph: 0, 2 and 4 IA @12 psi

Cold to Hot test: ±12 deg SA @ 8 deg/sec, 0 IA, 250 lb, 12 psi --repeat 8 sweeps

Spring rate at 25 mph: 0, 2 and 4 IA @12 psi

Warmup: ±8 deg SA, ±4 deg IA for about 1 minute @ 250 lb, 12 psi
Conditioning: SA1 @ 0 deg IA, 250 lb, 12 psi (2 sweeps)

Pressure = 12, 10, 14, 8, 12 psi

for Inclination angle = 0, 2, 4, 1, 3 deg.
Slip angle: SA1 @ 0 deg IA @ 250 lb (2 sweeps, conditioning)
(then return to the current IA)
for Load = 350, 150, 50, 250**,** 100
Slip angle: SA1
next Load
next Inclination angle
Spring rate at 25 mph: 0, 2 and 4 IA
Pause for data collection at the end of each pressure (this marks the end of a "run")
next Pressure

Note: A few tires debeaded at 8psi. When this happened, we remounted the tire and omitted the remainder of the 8 psi test. The next pressure, the final 12 psi test, was then conducted on that tire.

Tire wear was very good for all tires. There was plenty of tread left at the end of these tests.

4. Drive/Brake Test Plan

The drive/brake test plan outline with events in chronological order:

Speed: 25 mph for all tests
Note: Below, "SR1" means "sweep ± 20 % (+20% to –20% to +20%)"

Put TIRF transmission in neutral
Cold to Hot test: ±12 deg SA @ 8 deg/sec, 0 IA, 150 lb, 0 SR --repeat 8 sweeps

Warmup: ±8 deg SA, ±4 deg IA for about 1 minute @ 250 lb
Conditioning: SA1 @ 0 deg IA, 250 lb (2 sweeps)
Put TIRF transmission in gear

for Pressure = 12, 10, 14, 8, 12 psi
for Inclination angle = 0, 2, 4 deg.
Slip ratio: SR1 @ 0 deg IA @ 250 lb (2 sweeps, to conditioning)
(then return to the current IA)
for Slip angle = 0, 3, 6 deg.
for Load = 350, 150, 250, 50
Slip ratio: SR1
next Load
next Slip Angle
next Inclination Angle
Pause for data collection at the end of each pressure (this marks the end of a "run")
next Pressure

III. Tire Models

As in the past, tire models are expected from Stackpole Engineering Services and Milliken Research Associates, Inc. Unlike previous rounds, however, we are distributing the Calspan data before the models are ready. This is possible because of the electronic distribution of the data. When the models become available they will be posted on the secure forum. There may also be models offered by other parties.

IV. TestVideos

Calspan videotaped many of the tests (four DVD's worth). Samples may be posted in the future.

V. Suggestions for Analysis

A few items which you might find interesting when analyzing the data:

- Crossplot the data several different ways. Start with the "traditional" plots: lateral force vs. slip angle and longitudinal force vs. slip ratio. Then plot vs. normal load, inclination, pressure or even tread surface temperature. There are many, many ways to visualize and analyze the tire data.

- Compare the 12 psi runs taken at the start and end of each tire's test. What differences do you see between a new tire and a used tire operating at a nominal thermal equilibrium?

- Compare the performance of a cold, used tire (Runs 154-157) with a cold, new tire.

- Look at the tire spring rate tests, and the variation of the rates with load, inflation pressure, inclination angle, rim width and speed.

- The belt on the test machine at Calspan is very clean, so the peak friction values in the test data can be higher than what is seen in a typical parking lot. Try expanding the MRA Nondimensional tire model at lower values of road surface friction coefficient, comparing the results of, say, lateral force versus slip angle. Do the same with the SES Pacejka 96 tire model.

- Study the data at different rim widths to establish its effect on tire data.

VI. Questions/Comments

Please direct your questions to Dr. Edward M. Kasprzak, edward.kasprzak@millikenresearch.com