FSAE TIRE TEST CONSORTIUM ROUND 3 DVD

From: Edward M. Kasprzak, FSAE TTC Co-Director
To: FSAE TTC members
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This document describes the contents of the DVD, provides a guide to the tests and acknowledges the people and organizations who have made this effort possible.

In short, this DVD contains data from the third round of tests (August 2007), as well as the data from the previous two rounds. The first two rounds are included so that all the FSAE TTC data is accessible in one place.

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.

I. Acknowledgements

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

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

My personal thanks to my co-directors for all their time and hard work. Thanks also to Denny Trimble (University of Washington) who helped establish the FSAE TTC and has since moved-on.

The FSAE TTC 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 is included on this DVD.

Mike Stackpole—Stackpole Engineering Services. Mike Stackpole has donated a Pacejka '96 model of the data, included on this DVD.

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.

Calspan Tire Research Facility (TIRF). Thanks to Dave Gentz, George Tapia, Bob Woodill and everyone at Calspan for making this tire test possible. Calspan continues to support the FSAE TTC and are always interested to hear of schools applying the data to their FSAE entries. Calspan provided the consortium a price break for the testing (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.

II. Guide to Round 3 of testing

The third round FSAE TTC tests was conducted in early August 2007.   This project has the Calspan TIRF project number "1175". You will see this number throughout the raw data files.

Most of the data on this DVD is referenced by "run number". Each time a new tire or test sequence is started on the testing machine at Calspan TIRF a run number is assigned, starting with "1" at the beginning of a project. As a result, a typical output file might be named "1175run3.dat", which is the third run (test) of our project.

The following table relates run numbers to the tires tested in Round 3:

	Goodyear 20.0x7.0-13			Hoosier 20.5x7.0-13			Hoosier 20.0x7.5-13		Michelin 16/53-13	
rim width (in.)	6	7	8	6	7	8	7	8	7	8
Cornering, 12psi, multiple IA	7,55	4,54	1,53	13	11	9	15	21	19	17
Cornering, 10, 14, 16psi, 0 deg. IA	8	5,6	2,3	14	12	10	16	22	20	18
Drive/Brake/Combined	30	24	27	39	36	33	45	42	51	48
Drive/Brake/Combined wear study	31	25	28	40	37	34	46	43	52	49

Some run numbers are "missing" since those runs were either warm-up runs, tests to check the equipment or runs where a mistake was made in running the test.

The test plan was revised for Round 3 to include a study of rim width effects on tire force and moment output, and to study the repeatability and wear effects on the tires. Four different tires were tested:
Michelin 8x20-13 "B" compound (radial tire)
Goodyear 7x20-13 (directional tire—has different "inboard" and "outboard" shoulders)
Hoosier 7.0x20.5-13 "R25A"
Hoosier 7.5x20.0-13 "R25A"

The test plan for Round 3 was as follows:

1. Lateral Force I: 12 psi, range of inclination angles

Compared with the first two rounds of testing, the 450 lb. load has been eliminated and a 100 lb load added to the test plan. The plan is presented in "pseudocode" format:

```
Spring rate at 0 mph
Spring rate at 25 mph  (maintain 25mph for the remainder of the test)

Warmup: +/-2 deg SA, +/- 2 deg IA for about 2.5 minutes @ 250 lb
Conditioning: 2 SA sweeps (-4 -> +12 -> -12 -> +3) @ 4deg/sec @ 250 lb

Spring rate at 25 mph

Pressure = 12 psi
for Inclination angle = 0, 2, 4, 1, 3 deg.
        for Load = 350, 150, 50, 250, 100
                Slip angle:  sweep ± 12 degrees (-4 -> +12 -> -12 -> +3) @ 4deg/sec
        next Load
next Inclination angle
Repeat Spring rate at 25 mph
```

2. Lateral Force II: range of inflation pressures psi, 0 deg. inclination angle

This test follows immediately after Lateral Force I, so no warm-up or conditioning is needed. Here, different pressures are tested at 0 deg. inclination angle. Finally, the 12psi test at 0 deg. inclination angle from Lateral Force I is rerun—compare the results of these two tests to see how the tire has changed from the start to the end of the test.

Originally an 8psi run was planned, but after two tires debeaded at this pressure the 8psi runs were eliminated. The test plan:

```
No warm-up, no conditioning
```

Inclination angle = 0 deg.
for Pressure = 16, 10, 14 psi
Spring Rate at 25mph at each pressure
for Load = 50, 100, 150, 250, 350 lb. (350, 150, 50, 250, 100)
Slip angle: sweep ± 12 degrees (-4 -> +12 -> -12 -> +3) @ 4deg/sec
next Load
next Pressure

No warm-up, no conditioning
Spring rate at 25 mph
Pressure = 12 psi
for Inclination angle = 0 deg.
for Load = 350, 150, 50, 250, 100
Slip angle: sweep ± 12 degrees (-4 -> +12 -> -12 -> +3) @ 4deg/sec
next Load
next Inclination angle

This is a repeat of the first test condition to give an indication of tire wear effects

Repeat Spring rate at 25 mph

3. Drive/Brake/Combined I:

This is a standard drive/brake and friction ellipse test with slip ratio sweeps taken at three different slip angles and three different inclination angles. All sweeps are at 12 psi:

Spring rate at 0 mph
Spring rate at 25 mph (maintain 25mph for the remainder of the test)

Warm-up: +/-2 deg SA, +/- 2 deg IA for about 2.5 minutes @ 250 lb
Conditioning: 2 SR sweeps (+20% -> -20% -> +20%) @ 250 lb

for Slip angle = 0, 3, 6 deg.
for Load = 350, 150, 250, 50
for Inclination angle = 0, 2, 4 deg.
Slip ratio: sweep ± 20 % (+20% -> -20% -> +20%)
next Inclination angle
next Load
next Slip Angle

4. Drive/Brake/Combined II: repeatability and wear study

This test follows immediately after Drive/Brake/Combined I. Thus, no warm-up or conditioning are needed. The purpose of this test is to see how the tire changes as the test is run. The same series of conditions are run on the tire five times in succession. Trends across these five sweeps can be studied. Again, all sweeps are at 12 psi:

```
No warm-up, no conditioning
Pressure = 12 psi                    -Repeat this block 5 times
for Slip angle = 0, 6 deg.
        for Load = 150, 350 lb.
                for Inclination angle = 0, 4 deg.
                        Slip ratio:  sweep ± 20 % (+20% -> -20% -> +20%)
                next Inclination angle
        next Load
next Slip Angle
```

5. General Comments on the Round 3 Data

Behavior of the Hoosier and Michelin tires are assumed to be symmetric with respect to inclination angle. That is, for any combination of slip angle and inclination angle, swapping the signs (positive to negative or vice versa) of both will simply swap the signs of the lateral force, aligning torque and overturning moment. This assumption was made in the two previous rounds of testing for all tires, since they all were believed to have symmetric construction.

The Goodyear tire in this test does not have symmetric construction—there is a distinct inboard and outboard shoulder. This tire was tested at both positive and negative inclination angles. On the test machine the tire was mounted “letters in” and “letters out”, and the machine was tilted in the same direction in each test, corresponding to positive inclination angle. Negative inclinations were not run due to test machine limitations. **In the data files for runs 53, 54 and 55 the following values have reversed signs: slip angle, inclination angle, lateral force, aligning torque and overturning moment. These signs need to be reversed when analyzing the data,** since the tires were run rotating backwards on the machine to obtain inclination in the other direction**.**

All tires showed reasonable wear throughout the tests and had ample tread remaining at test conclusion.

Calspan rectified the load control issues that hampered the first two rounds of testing. Target loads are maintained much more consistently in this third round of testing.

III. DVD Contents

The contents of the DVD are now listed. This list is arranged according to the folders on the DVD.

Top Level

- This PDF describing the contents of the DVD
- PDF containing the text of the FSAE TTC website as it stood when you registered
- PDF stating the terms of use of this DVD's contents. *Read this document carefully*.
- Excel spreadsheet of summary tables provided by Calspan for Round 3.

The "Summary Tables" spreadsheet is provided by Calspan. It contains a list of the runs, run conditions and tires used for the tests. Tables of "reduced parameters", including tire spring rates and cornering stiffnesses, are provided.

fromCalspan

- A cover letter describing what was provided to the FSAE TTC (all contents appear on this DVD)
- Calspan TIRF logos (to make your own decals)
- Command files for the tests
- The TIRF website
- Reference documents on TIRF capabilities

Currently the TIRF website is being absorbed into a reworked Calspan website and is not available on the internet. The website included still shows the logos of their previous name, Veridian.

fromMillikenResearchAssociates

- A cover letter describing the contents provided by MRA—please read this for more information
- Ten .mat (Matlab) files containing MRA Nondimensional Tire Model coefficients for Round 3
- Two .p (Matlab) files containing the MRA Nondimensional Tire Model expansion
- One .m file which shows how to call the expansion routines

fromStackpoleEngineeringServices

- A single PDF containing the coefficients for Pacejka '96 models of the measured data, a statement of model equations and a discussion of the raw data.

RawData__________

Five folders, each containing raw data files in the following formats:

- ASCII (plain text, space delimited), Metric
- ASCII (plain text, space delimited), USCS
- ASCII (plain text, space delimited), Mixed ...used by Stackpole Engineering Services
- Matlab (.mat format), USCS
- Matlab (.mat format), Metric

TestVideos

A video of selected runs are provided. Files are labeled by their run number. All lateral force tests contain the entire warm-up sequence. For the longitudinal (drive/brake) runs the video starts at the conclusion of the conditioning sweeps. Videos are supplied for Lateral Force I and Drive/Brake/Combined I tests.

IV. Suggestions for Analysis

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

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

- Note the differences between the Michelin tire (radial) and the other (bias ply) tires. For example, plot lateral force vs. slip angle for one of each and compare the shapes of the curves.

- The Goodyear tire is asymmetric with respect to inclination angle. Note the differences between running a tire with inclination angle the “wrong way” (runs 1,4,7) and the “right way” (runs 53-55).

- 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.

- Look at the Drive/Brake/Combined II data to see if there are any differences in the data as the cycle of test sweeps is repeated five times. Similarly, compare the first sweeps in Lateral Force I with the last sweeps in Lateral Force II to see the effects of wear (and temperature).

- The Hoosier 20.5x7-13 tire was tested in Round 2 and again in Round 3. Compare the data from the two tests. Calspan’s load control is much better in Round 3. The belt in Round 3 was also “stoned” in an attempt to reduce its overall grip. How much did it help?

V. Questions/Comments

Please direct your questions/comments to Dr. Edward M. Kasprzak, kasprzak@localnet.com