FSAE TIRE TEST CONSORTIUM -- ROUND 5

From: Edward M. Kasprzak, FSAE TTC Co-Director
To: FSAE TTC members
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This document describes the data and files provided for Round 5 of testing, provides a guide to the tests and acknowledges the people and organizations who have made this effort possible. **Please read this document carefully before using the FSAE TTC data.**

All Round 5 data is available to FSAE TTC members via the private server at: http://sae.wsu.edu/ttc/
The public, introductory FSAE TTC website can be found at www.millikenresearch.com/fsaettc.html.

TTC members are reminded of the terms of their membership as stated on the FSAE TTC website:

> 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.

The TTC private forum, http://sae.wsu.edu/ttc/, exists for students to openly discuss the data without violating the terms of TTC membership.

All TTC members are strongly encouraged to display the Calspan logo on their vehicle--see "Calspan_logo.jpg" in the "fromCalspan.zip" download. Calspan has given the TTC a considerable price break, and you should consider them one of your sponsors.

Note: While two of the three Directors are from Milliken Research Associates, Inc. and the main webpage is hosted at MRA's web address, the FSAE TTC is <u>not</u> affiliated with Milliken Research Associates, Inc.

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
Mr. Doug Milliken, Milliken Research Associates, Inc.
Dr. Bob Woods, University of Texas, Arlington

Since Round 3, **Brian Seater** of Washington State University has contributed greatly to the FSAE TTC. He established and maintains the TTC's private 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 moved-on prior to Round 4.

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

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.

Continental AG joined the list of participating tire suppliers. They donated tires and shipped them to Calspan at no cost to the FSAE TTC.

In past rounds, **Michelin** and **Dunlop Motorsport** have donated tires and shipped them to Calspan at no cost to the FSAE TTC.

Keizer Aluminum Wheels provided 10" wheels at a discounted price. **Diamond Racing Wheels** produced the steel 13" wheels.

Calspan Tire Research Facility (TIRF). Thanks to Dave Gentz, Jim Stoetling, Eric Schuch, 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 fifth time Calspan has provided the consortium a price break for the testing (once 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 5

1. Overview

The fifth round FSAE TTC tests was conducted in late February 2012. The structure of the test matrices is nearly identical to Round 4. One important difference: In Round 5 there are multiple inflation pressures per data file.

Five different tires were tested, each on two different rim widths. The tires tested in Round 5 are:

- Continental 205 / 510 R13 (C11/C12)
- Goodyear D2704 20.0x7.0-13
- Hoosier 20.5 x 7.0 - 13 R25B
- Hoosier 18.0 x 6.0 - 10 R25B
- Hoosier 6.0 / 18.0 - 10 LCO

All 13 inch tires were tested on the same wheels as in Round 4—steel wheels purchased from Diamond Racing Wheels. All 10 inch tires were tested on aluminum wheels purchased from Keizer Aluminum Wheels. These are brand new for Round 5. Regardless of rim width or diameter, all wheels have the appropriate backspacing to align the wheel center with the center of the tire tread.

See the separate **RunGuide_Round5.pdf** to identify the tire/rim combination for each test run.

Highlights of the Round 5 test plan include:

- Full drive/brake/combined testing for 10 inch tires
- Each tire/rim combination was put through a full matrix of load, inclination angle and pressure combinations.
- 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. The number of these sweeps has been increased from Round 4.
- 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 “1464”. You will see this number throughout the raw data files. For example, a typical data file might be named “1464run7.dat”, which is Run 7 in the project.

2. Summary Tables

More information on each test can be found in the Excel spreadsheet “**1464 Summary Tables.xls”** provided by Calspan, found in “fromCalspan.zip”. 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 with needle probe immediately after the end of each run

3. Cornering Test Plan

The data is separated into two distinct test plans: “Cornering” and “Drive/Brake/Combined”. Data for each type of test is available for download in its own .zip file.

The cornering test was run with a free-rolling (no slip ratio) tire, while the drive/brake tests hold constant slip angle while varying slip ratio. Five loads, five inclination angles and four inflation pressures were tested.

The start of the test includes a “cold to hot” series of twelve 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.

Unlike Round 4, Round 5 includes multiple inflation pressures per data file. Recent upgrades to Calspan’s facilities (including a new pressure controller) made this possible, allowing less downtime during tests.

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 12 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

Pressure = 12, 10, 14, 8, 12 psi
  Slip angle: SA1 @ 0 deg IA @ 250 lb (2 sweeps, conditioning)
  for Inclination angle = 0, 2, 4, 1, 3 deg.
    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 14 psi (this marks the end of a "run")
next Pressure

Note: The 13" Diamond Racing Wheels did not interface well with the Goodyear D2704. This tire debeaded at 10 psi, 350 lb load. Test conditions were adjusted from the plan to keep this tire on the rim.

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 12 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
  Slip ratio: SR1 @ 0 deg IA @ 250 lb (2 sweeps, to conditioning)
  for Inclination angle = 0, 2, 4 deg.
    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 14 psi (this marks the end of a “run”)

next Pressure

5. Data Files

All data is reported in SAE sign convention (see SAE J670e, SAE 2047 or “Race Car Vehicle Dynamics” by Milliken/Milliken, page 62).

Data sets have been processed by Calspan, most notably to remove the “dwells” between slip angle or slip ratio sweeps and, in the case of the drive/brake data, to calculate SL, the SAE slip ratio channel. Data is presented in four different formats, each can be downloaded in their own .zip file:

ASCII, USCS units (data files begin with “A”, end in “.dat”)
ASCII, SI units (data files begin with “B” , end in “.dat”)
Matlab, USCS units (data files begin with “A” , end in “.mat”)
Matlab, SI units (data files begin with “B” , end in “.mat”)

There are also similar .zip files containing “wPauses” in the filename. These files, available for cornering only, have not been processed by Calspan and include all the data collected during the dwells between sweeps.

The data channels available are:

Channel	Units	Description
AMBTMP	degC or degF	Ambient room temperature
ET	sec	Elapsed time for the test
FX	N or lb	Longitudinal Force
FY	N or lb	Lateral Force
FZ	N or lb	Normal Load
IA	deg	Inclination Angle
MX	N-m or lb-ft	Overturning Moment
MZ	N-m or lb-ft	Aligning Torque
N	rpm	Wheel rotational speed
NFX	unitless	Normalized longitudinal force (FX/FZ)
NFY	unitless	Normalized lateral force (FY/FZ)
P	kPa or psi	Tire pressure
RE	cm or in	Effective Radius
RL	cm or in	Loaded Radius
RST	degC or degF	Road surface temperature
SA	deg	Slip Angle
SL	unitless	Slip Ratio based on RE (such that SL=0 gives FX=0)
SR	unitless	Slip Ratio based on RL (used for Calspan machine control, SR=0 does not give FX=0)
TSTC	degC or degF	Tire Surface Temperature--Center
TSTI	degC or degF	Tire Surface Temperature--Inboard
TSTO	degC or degF	Tire Surface Temperature--Outboard
V	kph or mph	Road Speed

6. Test Comments

A few important thoughts on the Round 5 tests:

The Continental tire chattered past the peak slip angle at higher loads. This can be seen as a sudden drop in the lateral force vs. slip angle curves. It is important to note that just because a tire chatters at Calspan it does not mean it will chatter on your car. Calspan has a different amount of grip, different system stiffnesses and different inertias compared with your car and driving environment. All data up to the chatter can be used normally. Chattering data should be ignored. We do not feel this chattering reflects poorly in any way on the Continental tire.

There was a tire/wheel incompatibility issue between the Goodyear D2704 tire and the TTC's steel Diamond Racing wheels. The Goodyear debeaded at 10 psi and high load (350 lb). The test procedure was modified to avoid this load and pressure combination, and the 8 psi tests were abandoned altogether. As with the Continental tire, we do not feel this reflects poorly on the Goodyear tire. In future TTC tests we will probably source a second set of 13" wheels should such an incompatibility arise.

This is the first time the TTC has conducted both cornering and drive/brake tests on 10" tires. Modifications were made to Calspan's test machine to allow the test head to drop closer to the roadway, making these tests possible. We appreciate Calspan's extra effort to make this happen.

The belt on the test machine at Calspan is very clean and very smooth, so the peak friction values in the test data can be higher than what is seen on a typical racing surface (or parking lot). In past Rounds the "real world" peak lateral and longitudinal forces reported by FSAE teams are roughly 2/3 of those seen at Calspan. Such disagreement is always an issue with laboratory tire testing—how well or poorly the magnitudes agree are a strong function of tire construction and compound.

III. Tire Models

Various tire models or modeling tools may be posted on the FSAE TTC private forum. The FSAE TTC does not provide tire models.

IV. Test Videos

Calspan videotaped many of the tests (six 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?

- Plot the lateral force vs. slip angle data during the “cold to hot” sweeps. How does the tire change with temperature and break-in?

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

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

VI. Questions/Comments

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