Welcome to atiheitz.com

Automotive Testing, Inc.
Heitz Automotive Testing, Inc.

Click here for downloadable information, reports, and steering machine software!

The full text of everything contained in this website is also available for download in Adobe Acrobat PDF format on our **Download Page**.
Steering machine software is also available for download on our **Download Page**.

Click here for directions & maps from Newark Airport and Philadelphia Airport to ATI/Heitz.

AUTOMOTIVE TESTING, INC. / HEITZ AUTOMOTIVE TESTING, INC.

6 MOORES MILL ROAD
PENNINGTON, NEW JERSEY 08534-9738

PHONE: (609) 466-2071
FAX: (609) 466-4866
e-mail: ati@atiheitz.com

Last modified 04/06/2006

1.1 WHO WE ARE

Automotive Testing Incorporated and Heitz Automotive Testing (formerly doing business as Heitz Chassis Lab) originated as separate corporations which were complementary in function. Automotive Testing (ATI) provided fully-instrumented road, track, and proving grounds measurement of vehicle behavior, while the Chassis Lab provided laboratory measurement of all the individual vehicle parameters (except tires) involved in prediction of vehicle behavior by mathematical simulation models and in evaluation of vehicles against theoretically-defined criteria. Instrumentation, data acquisition hardware, and data processing software used by the two corporations are completely compatible.

In the period 1990-1996 ATI designed a "Programmable Steering Machine" to automate its rollover testing. In 1998 ATI used the new steering machine to develop a reversed-steer rollover test with roll rate feedback. This testing concept has become a world standard for rollover testing.

When other testing organizations requested copies of the steering machine, Heitz Chassis Lab developed an improved machine for manufacture. The *Heitz Sprint 3* steering machine soon became the *de facto* standard for rollover and ESC testing, with over 40 units sold worldwide.

"In recent years, the use of programmable steering machines has become increasingly common in the automotive testing community. NHTSA, most automakers, and many private organizations now have extensive experience with these machines, and their respective test programs presently rely on the accuracy, repeatability, and reproducibility automated steering is capable of delivering." (*An Assessment of Human Driver Steering Capability*. DOT HS 809 975, June 2005)

In 2005 it was decided that ATI would take over all testing activity, while Heitz Automotive Testing would concentrate on manufacture of equipment for general automation of vehicle testing. New developments in simultaneous control of steering, throttle and brakes, either on-board or by remote control, are now in prototype testing,

1.2 ATI MISSION STATEMENT

C.S. Lewis, in his book The Four Loves, says that "the human mind is generally far more eager to praise and dispraise than to describe and define. It wants to make every distinction a distinction of value". ATI's mission is the opposite: it is not to make value judgments to "praise or dispraise"; it is to "describe and define" by objective, carefully instrumented measurements. We are advocates only for measurement accuracy.

1.3 TESTING PROTOCOLS

All ATI testing is performed in accordance with established standards or recommended practices, whenever such standards or recommended practices exist for obtaining the desired data. The Chassis Lab methodologies and the instrumentation accuracies listed herein are in accordance with SAE J1574 for all items covered by J1574, although the range of applied forces, moments, and displacements is greater. Roadholding tests are performed in accordance with numerous standard protocols as noted herein. We do not perform result-oriented tests.

1.4 TEST DOCUMENTATION

Each test program is documented by one or more spiral-bound test reports and by unedited videotapes. Raw and processed data is made available on CDs.

All tests are videotaped, and all raw instrumentation data is anti-alias filtered, sampled 60 times per second, and recorded in 12-bit binary serial format in one to three video lines at the top of the screen, in a patented, proprietary process. Each video line carries 12 channels of data. Raw instrumentation data is also superimposed onto the video picture, in columns of twelve 3-digit numerics or in several other graphic forms, either during the test or during editing. Test videotapes are provided with and without on-screen timing, and with and without superimposed numerical data. Video formats can be VHS, S-VHS, or digital.

Test reports are completely objective (no value judgments) and include: purpose of the test; vehicle description and any departure from manufacturer's specification; description of methodology and instrumentation; plotted data; equations fitted to plotted data (in parameter measurements); still photographs of test set-ups; and copies of the protocols used.

In preparation of the reports raw data is filtered as required, by running average or Fourier methods, and zeroed. In cases where dynamic data is to be compared, the phase shifts caused by anti-aliasing filters are removed. The resulting data set, along with any auxiliary variables that must be obtained from recorded data by integration, etc., is saved as the "processed data set" for use in preparing data plots. Floppy disks containing both the original raw data and the processed data set are supplied on request, in binary or compressed ASCII files.

1.5 COMPANY HISTORIES

ATI began in 1970 as a spin-off from a Princeton University research project called "The Dynamics of the Car-Driver Combination". It was incorporated to "perform instrumented documentation of automobile handling performance" in 1978.

Primary interest has been in accurate, well-documented measurement of vehicle handling qualities, and in instrumentation methodologies to give better data and better insight into the measurement processes.

In the early 70's work concentrated on developing compact, light weight data acquisition and recording systems, with magnetic tape and "quick-look" eight-channel stripchart recorders, all powered from the vehicle's cigarette lighter. This was followed by improving in-vehicle motion picture photography with specially-designed, graduated "windshield filters", and in the late 70's by a switch to video and real-time split images using synchronized video cameras.

From 1981-85 a switch was made from analog to digital data recording, and development work was concentrated on combining the magnetic tape, "quick-look" stripchart, and audio/visual video recording into one source. This work culminated in patenting and putting into service the unique "Dataline System", which combines sight, sound, and instrumentation data for playback in synchronism for time & motion study of vehicle handling questions. With 20 years of reliable service behind it, the Dataline System remains the mainstay of our data acquisition technology. One unique advantage of this system is the ability to single-frame the "driver's view" in a severe test maneuver, with on-screen display of all motion parameters from instrumentation. A second advantage is the ability to re-live a test program from the driver's seat months or years after its actual performance.

The "Video G-G Diagram", also patented in 1985, was a logical offshoot of the basic Dataline. This device overlays the vehicle G-G diagram on a through-the-windshield video picture, along with bar-graphs for throttle and brakes at the top of the picture and lap times & splits at the bottom. It has proven to be a useful tool for race car/driver in development and race practice.

ATI had been performing CG and various chassis parameter measurements on an as-requested basis since the 1970's. In 1992, anticipating that mathematical simulation models would soon come into wide use, it was decided to organize a complete chassis parameter capability, including all inertial, kinematics, compliance, steering, and shock absorber/strut items. Heitz Automotive Testing was formed as a separate, but complementary, entity, organized to do in-lab parameter testing as Heitz Chassis Lab, with ATI concentrating on vehicle handling testing. Acting together, using identical data acquisition hardware and complementary software, ATI/Heitz offers capability for complete evaluation of vehicles or simulation models.

ATI has always concentrated on standardized tests performed to industry protocols. For many years we have been active in preparing standards for handling qualities measurements, as a participant in the SAE Vehicle Dynamics Committee and in the American Advisory Group to the ISO committee for vehicle roadholding standards (ISO/TC22/SC9). ATI now offers all current SAE and ISO test protocols.

A steering machine is necessary for some ISO test protocols, and an easily-installed, high-performance, programmable steering machine can provide more precise, more repeatable results in many other test protocols. Furthermore, such a steering machine is necessary for any kind of objective rollover testing. Therefore in 1992 ATI built a crude prototype steering machine for its own rollover testing, and by the end of 1996 had developed a "proper" version. When several companies requested copies, and based on experience with that unit, Heitz began manufacture of the *Sprint* steering machine.

By 2005 Heitz was fully involved with steering machines and other devices for test automation, and so ATI took over all testing activities.

As illustrated throughout this Website description, ATI/Heitz offers, and will continue to offer, leading-edge capabilities in the study of vehicle roadholding performance.

1.7 PRINCIPAL ENGINEERS

1.7.1 Automotive Testing, Inc. - Edward J. Heitzman

ACADEMIC BACKGROUND
M.E. degree, Stevens Institute of Technology, 1956. Graduate work in Mathematics, Engineering Mechanics, and Servomechanisms at Wayne State University, Detroit; Theoretical Aerodynamics at University of Detroit; Airplane Dynamics, Pilot Dynamics, Automatic Controls, and Aerospace Instrumentation at Princeton University.

PROFESSIONAL EXPERIENCE
June 1956-September 1964: Research Engineer at the General Motors Research Staff. Work included steering & suspension systems, vehicle response to control inputs, chassis design and stress analysis, aerodynamics and wind tunnel testing. Senior Research Engineer at the General Motors Design Staff. Work included establishing structural frequency response criteria and development of structures and suspensions for future production cars.

September 1964 to January 1966: Attended Princeton University under General Motors Mid-Career Fellowship. Research in mathematical models for car/driver behavior. During summer of 1955 gave series of lectures at General Motors on car/driver modeling.

January 1966-June 1970: Member of Research Staff, Princeton University Department of Aerospace and Mechanical Sciences. Project Leader in a University research program called "Dynamics of the Car-Driver Combination", which was aimed at a fundamental understanding of the driving task and of the effect of vehicle response dynamics on the performance of the car/driver system. Work included design of a research automobile with four-wheel steer and a fully-active suspension system, using hydraulic servoactuators controlled by a 300-amplifier analog computer system. Technical responsibilities included design and construction of all mechanical, hydraulic, and electronic systems in this vehicle, general design of the experiments for which the vehicle was intended, design of the digital data acquisition system and its computer interface, and specification of test documentation requirements and associated computer programs.

October-December 1966: Special Consultant to National Highway Safety Bureau. Assisted in preparing the initial set of Motor Vehicle Safety Standards. Was primarily responsible for original versions of tire standards S-109 and S-110.

January 1967 to January 1970: Charter member of National Motor Vehicle Safety Advisory Council.
This Council, in which members were appointed by the President, was organized to advise the Secretary of Transportation on policy matters regarding motor vehicle safety standards.

February 1966 to July 1978: Partner in Automobile Development Associates, consulting in automobile design and design issues; and from 1970 on in handling qualities testing and in instrumentation for vehicle testing.

July 1978 to present: Principal Engineer, Automotive Testing, Inc. Responsible for customer interface, design and execution of test programs, mechanical design of instrumentation and test facilities.

March 1991 to present: Consultant to Heitz Chassis Lab and Heitz Automotive Testing. Performs mechanical design; assists in performance of tests and preparation of reports.

PROFESSIONAL AFFILIATIONS
Member of Society of Automotive Engineers, American Institute of Aeronautics and Astronautics, and Human Factors Society. Member of the SAE Vehicle Dynamics, Ride & Handling Committee and the American Technical Advisory Group to the International Standards Organization Committee ISO/TC22/SC9 - Vehicle Dynamics and Roadholding. Editor of SAE Recommended Practice J266 (1995) - Steady-state Directional Control Test Procedures for Passenger Cars and Light Trucks.

PATENTS
"Forced-air cooled drum brake" (3,043,630); "Emergency hydraulic fluid supply system" (2,995,382); "Weight transfer compensated brake system " (3,133,766). "Driver-vehicle behavior display apparatus" (4,716,458) and "Real-time video-data acquisition system"(4,814,896) were co-invented with Edward F. Heitzman.

1.7.2 Heitz Automotive Testing Inc. Edward F. Heitzman

ACADEMIC BACKGROUND
BE in Computer Science, Stevens Institute of Technology, 1983. MSE in Computer Science, University of Pennsylvania, 1985.

PROFESSIONAL EXPERIENCE
June 1983 to present: Consultant in computer integration and software to several organizations in fields of education and medical office billing systems.

June 1985 to Present: Electronic Design, Data Processing, and Test Engineer, Automotive Testing Inc. Was primarily responsible for all logic design and circuit design, and was totally responsible for all printed circuit layout, assembly, testing, and maintenance various data acquisition and video systems. Wrote all software for data processing system: data entry from videotape, frequency domain filtering, number crunching, data plotting and presentation. Participated in all vehicle test programs as instrumentation technician.

March 1991 to December 2005: Principal Engineer, Heitz Chassis Lab. Responsible for setup and conduct of tests, data acquisition, data processing, data presentation.

January 2006 to present: Principal engineer , Heitz Automotive Testing. Performs all electronic circuit design and software, supervises layout, fabrication and testing, handles all sales, upgrades & repairs, etc.

PROFESSIONAL AFFILIATIONS
Member of the Association for Computing Machinery and the IEEE Computer Society.

PATENTS
Co-inventor of "Driver-vehicle display apparatus" (4,716,458), and "Real-time video data acquisition system" (4,814,896).

Last modified 5/11/2006

2. Roadholding Testing Offered by ATI

2.1 TESTS OFFERED

2.1.1 Definitions

"Control response" and "roadholding" refer to the open-loop response of the vehicle to inputs from steering, throttle, and brakes.

"Handling" refers to the closed-loop behavior of the vehicle and driver, which involves the visual, kinesthetic and proprioceptive communication from vehicle to driver in addition to reliable control response. For example, a "couch-potato car" may have control responses that are in many respects proper, but will have poor handling. Similarly, a car may have good control response, but still "have no soul". Obviously, "good handling" is often a subjective opinion. Objective measures of handling usually involve the driver workload requirements in a given closed-loop driving task.

"Rollover" refers to those "limit" maneuvers that challenge a vehicle's rollover resistance. In rollover tests the severity of the control inputs are increased until the response limit - plowout, spinout, or rollover – is reached. Rollover testing may use either closed-loop avoidance maneuvers or open-loop maneuvers: but only open-loop tests can be objective and driver-independent.

2.1.2 Control Response Testing Currently Offered

SAE J266- Steady State Directional Control Test Procedures

- Constant radius test (ISO 4138)
- Constant steer angle test
- Constant speed, variable steer test
- Response gain/speed test

ISO 7401 - Lateral transient response test methods

- Step input
- Random input
- Pulse input
- Continuous sinusoidal input
- Single-cycle sinusoid

ISO 7975 - Braking in a turn - open loop test procedure

ISO 9816 - Power-off reactions of vehicle in a turn- Open-loop test procedure

ISO 9815 - Passenger car-trailer combination - lateral stability test procedure

2.1.3 Handling Tests Currently Offered

ISO 3888 Part 1 – Test procedure for a severe lane change

ISO 3888 Part 2 - Elk Test

NHTSA ESC Test Series

2.1.4 Rollover Tests Currently Offered

NHTSA Rollover Test Series -
Slowly Increasing Steer
Road Edge Recovery Maneuver

ATI Rollover Test Protocols (See Part 6)-
ATI Reversed Steer

Notes:

- SAE is Society of Automotive Engineers
- ISO is International Standards Organization
- NHTSA is National Highway Transportation Safety Agency

2.1.5 Additional Roadholding Testing Services

Split Image Videography - is performed in real time using multiple synchronized video cameras; usually at little or no extra testing costs.

Braking Tests - Simultaneous measurement of braking factors: pedal effort, booster vacuum, pressure at each brake line, speed of each wheel, vehicle speed, and brake temperatures. Measurement of vacuum booster exhaustion effects. Measurement of ABS internal electronic signals.

Aerodynamic Effects - Specially-designed, fast-response airspeed/direction system is used in conjunction with steering wheel angle and inertial sensors to study wind response, aerodynamic interaction with trucks, etc. One vehicle's response is compared to another "reference vehicle" by the methodology described in ISO/TC22/SC9/WG5 N11 (21 May 1991).

Acceleration/Braking Lift/Dive - Suspension deflections and pitch angle gradients due to acceleration and braking.

Vehicle Performance - Time to speed and distance, braking stopping distances, etc.

Accident Site Driving Task Analysis - Accident site drivethroughs using fully-instrumented exemplar vehicles, with "driver's eye view" and roadside video coverage.

Tire Deflation - Performed on test track or highway, by multiple solenoid valves mounted in tire rim, activated on switch command through a slipring assembly.

Tire Standard MVSS 109 - The Bead Unseating Test and the Breaking Energy Test of Motor Vehicle Safety Standard S-109, performed on in-house laboratory test fixtures.

Component "Failures" - Staged failures of steering, brake, or suspension components with documentation of vehicle performance by instrumentation and real-time split-image (2 pictures-within-picture) video.

Vehicle Systems - Comprehensive testing of electric and electronic; hydraulic and pneumatic; fuel; engine management; diagnostic; servo control; active and passive safety systems.

Four-Wheel Steer, Traction Control, Stability Augmentation - Analysis and testing of electronically augmented or controlled steering, brake, throttle, and suspension systems. Experimental determination of operating algorithms.

Data Presentation - By "Mitsubishi Rhombus", "Weir Diagram", "Video G-G", and other methodologies.

Analysis of Testing by Other Facilities - Analysis of methodology, instrumentation capabilities, etc. Plotting of raw data; assessment of validity; interpretation of results.

2.2 TEST SITES

ATI's standard test programs are carried out on the drag strip and adjacent parking area at Raceway Park in Englishtown, NJ. The drag strip is constructed of extremely smooth blacktop, 80 feet wide and 4,000 feet long. It is level in the longitudinal direction, and has a constant one-degree cross slope for drainage. Adjacent to the dragstrip is a paved (March 1996), level-surface parking area, 400 feet wide and 2,000 feet long, with an entrance road for acceleration to speed. All testing in which the steering machine is used are run in the parking area. Test programs may also be run at Transportation Research Center in East Liberty, Ohio, and at other locations as requested by clients.

2.3 DATA RECORDING

2.3.1 Data Channels

In vehicle handling tests the following data channels may be recorded or plotted:

- Vehicle speed
- Steering wheel angle
- Throttle position
- Brake pedal effort
- Yaw velocity
- Roll velocity
- Fore acceleration (stable platform or strap-down)
- Lateral acceleration (stable platform or strap-down)
- Inertial Roll angle
- Steer effort
- Sideslip angle
- Distance covered
- Accelerations measured on stable platform are referred to CG by differentiated roll and yaw velocities. Sideslip is computed from inertial measurements.

In tip-up testing the following additional data may be recorded or plotted:

- Inertial Pitch angle
- Suspension travel
- Tire vertical deflection
- Tire lateral deflection
- Roll acceleration

2.3.2 Transducers Used in ATI Handling Tests

Speed and distance: ATI-developed all-weather fifth wheel with a 45 pulses/foot optical encoder sealed inside the hub. Distance output 10 or 1 pulse/ft by BCD rate multiplier, calibrated to ±1 ft. over a taped 1877 ft distance. Speed obtained thru frequency-to-voltage converter, with crystal calibration to 100 mph full-scale. Metric calibration by resetting rate multiplier.

Wheel speed/Tire deflection/suspension travel: A hollow-shaft encoder runs on a plate supported by lugnut extensions. The body of the encoder is in a frame that is connected through a pin/clevis joint to a vertical shaft. The vertical shaft travels through a fender-mounted eyebolt assembly which contains a string encoder for measurement of suspension travel. The encoder measures wheel speed. A downward-facing ultrasonic distance sensor measures tire deflection.

Steering wheel angle/effort: "second steering wheel" normally clamps to original steering wheel, with adjustable arm to suction cup on windshield. Optional attachment is directly to the steering column, replacing the vehicle steering wheel. Strain-gauge paddle wheel element with built-in amplifier measures steer effort. Optical encoder angle readout. Calibration by special torque wrench. Used in lane-change and free-control studies.

Throttle position: Tap into vehicle's throttle position potentiometer.

Throttle position: String encoder attached to accelerator linkage.

Brake effort: LEBOW 3363-200 brake pedal load cell. 200 pounds full-scale; linearity 0.1 percent. Cal by precision 100 lb TROEMER 9082 NBS Class F weight.

Brake effort: LEBOW 3363-300 brake pedal load cell. 300 pounds full-scale; linearity 0.1 percent. Cal by precision 100 lb TROEMER 9082 NBS Class F weight.

Yaw velocity: NORTHRUP Nortronics 3-axis DC-DC rate gyro package, P/N 77025, SN17 and SN18 (2 units, one installed in Humphrey Package). 90 deg/sec FS; linearity 0.5 percent; hysteresis 0.1 deg/sec; threshold 0.01 deg/sec. Calibration on 36 degrees/sec rate table.

Yaw acceleration: SYSTRON-DONNER INERTIAL DIVISION Fluid-Rotor Angular Servo Accelerometer, Model 4591. Full-scale 570 Degrees/sec/sec; Linearity 0.2 percent. Calibration check on pendulous swing.

Linear acceleration: Force-balance servo accelerometers: SYSTRON-DONNER Models 4383 and 4310; SUNDSTRAND Models 303 and 305, SUNDSTRAND Model 2180 "MiniPal". Several of each, with full-scale 0.25 to 10 G, linearity 0.05 or 0.1 percent. Calibration on sine table with precision gauge blocks.

Stabilized Inertial Reference System: Pitch & roll Angles, X,Y,Z accelerations, pitch, roll, yaw velocities: HUMPHREY Stabilized Accelerometer System, Model SA07-0304-1. Vertical/free gyro can be used with servo erection (at 2 deg/min) or as low-drift free gyro caged until beginning of maneuver. Angles are calibrated against accelerometers by forced drift. Gimballed accelerometers held vertical by gyro are SUNDSTRAND Linear Servo Accelerometer Model 303. Full scale 1 g, linearity 0.05 percent. Calibration ± 1 g by tilting. Package is modified by installing NORTRONICS rate gyro package (S/N 17) inside and incorporating power supplies in box lid. Weight 38 pounds,

Strap-down Inertial Measurement System (IMU1): X,Y,Z accelerations, Roll, Pitch, Yaw Rates. Assembly consists of three orthogonally-mounted SUNDSTRAND Model 303 linear servo accelerometers, together with three Systron Donner GyroChip rate sensors.. Dimensions 4x4x3.5 inches, 3.2 pounds.

Strap-down Inertial Measurement Ststem (IMU2): X,Y,Z acceleration, pitch, roll, yaw velocities. Assembly consists of three orthogonally-mounted Sundstrand Mini-Pal servo accelerometers and three Systron Donner GyroChip rate sensors. Dimensions 3.5x4.5x2 inches, weight 1 pound.

Sideslip angle and ground-referenced roll angle: ATI-designed BETA TROLLEY TYPE 1. Angular accuracies 0.1 degree, ground-generated noise permitting.

Wind speed and direction: Assembly consists of a lightweight rotating cup anemometer and a fast-response, fiberglass-over-styrofoam wind vane, specially designed by Princeton University Aerospace Department.

2.4 Specialized Test Equipment

2.4.1 Data Acquisition System

All data is conditioned in instrumentation amplifiers, and anti-alias-filtered in tenth-order 14.2 hz Butterworth active filters. Available conditioners include DC General Purpose; DC Strain Gauge; Shaft Encoder; Frequency Input. The filters use precision operational amplifiers, one-percent resistors, and temperature-stable capacitors matched to 0.1 percent. The filter characteristic is flat to one part in 4000 at 10 hz and is down 66 db at 30 hz. The filtered data is sampled 60 times per second, digitized to 12 bit accuracy and resolution, and stored with 12 channels on one horizontal line of the video recorder. Each data line appears as a dot-dash line across the top of the visible video picture.

The digitized data can be shown as an overlay on the video picture, either as a 12 channel horizontal analog bar display, or as a vertical array of numerics, each ranging from -1000 to +1000 full scale. Both displays can be used simultaneously, if desired. The numeric display can be updated 60 times per second, on every video field, for single-framing analysis, or at slower rates (4 times per second and 2 times per second) for real-time viewing. In running the test, these displays are shown on a video monitor usually placed on the floor of the passenger side, for a visual check of proper transducer operation.

Only the data line must be recorded, as the other displays can be regenerated during playback, or recorded on the picture during editing.

The system has a plug-in 12 channel 12 bit Digital to Analog converter module, to provide strip-chart recording capability or analog recording into other data systems.

The system also has a plug-in "RAM Buffer" module, which serves as an interface to an IBM - PC computer. Thru this module, the computer sees the data being reproduced as RAM that is updated with twelve 12-bit data samples in a 53 microsecond burst occurring sixty times per second. Various "handshake" lines and data flags are provided for easy software access.

Unique Capabilities of Data Acquisition System - In many test programs there is visual and auditory "data" which can be seen or heard but not measured. The ATI "Real-time Video Data Acquisition System" (US Patent 4,819,896) overcomes this problem by recording all three sources of information - sight, sound, and instruments - simultaneously and in synchronism, on videotape.

Display Capabilities - The real-time data display overlaid on the video picture has proved to be particularly useful . For example, in accident scene drivethroughs, in demonstration of avoidance maneuvers, and in standard lane-change tests the video picture can be single-framed, with steering wheel angle, lateral acceleration, and other variables shown in 1/30 second increments against the driver's view of lane boundaries or other obstacles.

Video G-G Diagram - The ATI "Driver-Vehicle Display Apparatus" (US Patent Number 4,716,458) shows the instantaneous cornering/braking/acceleration state of a car with respect to its various limits, overlaid on the "Driver's eye view" video picture. With acceleration/braking as the vertical axis and lateral acceleration as the horizontal axis, various diagrams bit-mapped in PROM are used to represent the driver unwillingness limit, the vehicle's control limit, the rollover limit, etc. The actual forward and lateral accelerations experienced by the test vehicle are combined into a moving dot on the screen. The instantaneous relationship between the vehicle and its limits are immediately obvious. The "Video G-G Diagram" has been utilized in demonstrating safety margins in vehicle scene drive-throughs, in showing the severity of lane change maneuvers, and in demonstrating the margins between vehicle handling limits and rollover limits.

Race Car Video G-G - In the adoption of the video G-G diagram, horizontal bar graph representations of throttle and brake are added at the top of the screen, and lap time in a numeric display at the bottom of the screen. The lap time is reset by a radio signal sent by a stopwatch operator at the side of the track.

Real-Time Split Image - The output of up to three video cameras can be combined into one composite picture, maintaining the capability for data overlay. Typical applications have a master "driver's eye" view through the windshield, with smaller picture-in-picture views to show disconnected components, wheel lift, etc. The Heitz PIP system is done in real time, using three cameras and one recorder, for economy and to enhance admissibility.

2.4.2 Programmable Steering Machine

See Heitz Section and downloadable PDF files.

2.5 Rollover Resistance Test Evaluation

2.5.1 Overview of Rollover Analysis

Objective rollover analysis includes the following areas: vehicle form and function; criteria for vehicle rollover resistance; vehicle rollover testing; vehicle handling characteristics; and the role of vehicle trajectory and tripping mechanisms in accidents.

1. The first rule in all industrial design is "Form Follows Function". Accordingly, a vehicle designed for off-road use at the expense of on-road performance will be relatively narrow and short for maneuverability; it will have large road clearance and measures to protect running gear; and it will have oversize tires for flotation in mud or loose sand. Small vans and short station wagons will be taller than passenger cars because passengers must "sit up straighter"; and vans will also be taller for easy entry. These characteristics, dictated by the vehicle's intended use, will generally result in a higher center of gravity and a tendency toward compromised rollover resistance in vehicles designed primarily for off-road use or for utility than in passenger cars or sports cars.

2. A vehicle's rollover resistance should be evaluated by various objective criteria, in the light of its expected use. The design aim must be maximum practical safety for the vehicle’s demographic target and intended use.

3. Static rollover resistance depends primarily upon center of gravity and trackwidth; on suspension roll compliance; and on lateral elasticity of tires and suspension. Dynamic rollover resistance depends upon these factors, plus roll inertia and shock absorber characteristics, and the vehicle's handling responses.

4. There have been five different static criteria for vehicle rollover resistance. “T/2h” (the ratio of the half-track dimension to the CG height) can best be described as the rollover resistance of the equivalent brick: it is no more than a first-order approximation because it completely disregards the static lateral elastic properties of tires and suspension, as well as all vehicle dynamic aspects. "Tilt table ratio" takes into consideration the static lateral elastic properties, but introduces a confounding, unnatural rise in the vehicle CG proportional to the departure of the cosine of the tilt angle from unity. Tilt table ratio has the advantage of simplicity and repeatability, but it is "repeatably wrong". "Side Pull Ratio" is a relatively difficult and complicated test, but when performed correctly with precision equipment it provides the best available estimate of static, as contrasted to dynamic rollover resistance. "Critical sliding velocity" (CSV) adds vehicle roll moment of inertia to track width and CG height, and provides a theoretical estimate of the minimum lateral sliding speed at which a tripped rollover will occur. "Steady-State Rollover Safety Margin" is the margin between the maximum steady-state cornering capability of the vehicle as measured in one of the SAE J266 handling test protocols, and the sidepull ratio as measured in laboratory tests.

5. Sidepull has the advantage of measuring separately the effects of body roll angle and the lateral compliance of suspension and tires, and the vertical movement of the sprung mass due to side load. Sidepull therefore yields true measurements of T/2 and

H, under static conditions.

6. Critical Sliding Velocity can be improved by using the values of T/2 and H measured in a sidepull test as opposed to "undeformed" values obtained from measurements without applied sideload.

7. Because of these considerations, Side Pull Ratio is the most objective static laboratory criterion presently available for evaluation of “steady-state rollover resistance”, and CSV using sidepull data is the most complete overall criterion using only laboratory test procedures. Although Sidepull Ratio is theoretically the most objective static criterion, it requires very sophisticated testing equipment, currently available at only a few places, such as General Motors and Heitz Chassis Lab.

8. In the period 1971-1974 NHTSA made a concerted effort to develop a consistent dynamic test procedure for vehicle rollover. The "VHTP" procedures: braking in a turn, trapezoidal steer, sinusoidal steer, and "drastic steer & brake maneuver", all using a primitive automatic vehicle controller to remove the human element, were developed. The conclusion of this effort was that rollover testing is essentially a "can of worms" for two reasons -- tire variability and roll/yaw synergism. (1) In recent years, however, both of these difficulties have been overcome.

9. Tire peak sideforce was found to increase with successive runs during a test due to shoulder wear, by as much as 40 percent with some square-shouldered 1970-vintage bias-ply tires. It was later found that radial tires tend to behave oppositely, but with less variability, due to their as-designed rounded shoulders. Tires with different tread patterns would change at different rates (squared-shoulder greater than rounded-shoulder), such that a consistent test procedure was impossible to develop. (Recent ATI rollover tests with modern radial tires have found stable lateral acceleration measurements in repeated test runs). (2)

10. Roll/yaw synergism made the timing of steer reversals an important factor in rollover. It was found that a human driver, after a few practice runs to get a "feel" for the vehicle, could roll a passenger car that would not roll under the automatic controller's program. However, a quandary arose in the driver-control testing. After “getting the feel” the driver could achieve rollover in every run; but after a tire change it would take two or three runs to “get the feel” again. The question was whether the “learning” was taking place in the driver or the tires. This problem was solved 1n 1997 with the introduction of the Heitz Programmable Steering Machine, which provides precisely-repeatable steering inputs.

11. In 1988 and again in 1996, *Consumers Union* called certain vehicles Unacceptable, in the subjective opinion of CU's experts, because they tipped up in CU's obstacle avoidance maneuver. Critics pointed out that the tests were not instrumented, so the exact maneuvers could not be duplicated for evaluation; that test results were very driver-dependent; and that other vehicles with less rollover resistance had been deemed OK by Consumers Union experts.

12. In 1992 a NHTSA-sponsored report by Systems Technology, Inc. described “Steady-state Rollover Propensity Margin” as a rollover criterion.(3) This margin was defined

as the difference between Sidepull at tip-up and the maximum lateral acceleration ("max lat") in a circle test. This criterion was immediately put to use by ATI as a useful steady-state criterion, and it was later adopted by General Motors as a design guide.

13. In 1997 Toyota unveiled their "Fishhook" test, which consists of a violent swerve to miss an obstacle pylon, followed by a steer reversal to full lock in the other direction. The Fishhook test is instrumented, and the criterion obtained is the lateral acceleration at tip-up. According to the test protocol, if tip-up is not achieved, pulse braking is used to stimulate tip-up. (4)

14. In 1998 the Swedish magazine *Teknikans Verld* rolled one of the new A-class Mercedes in an obstacle avoidance maneuver called the "Elk Test". Mercedes responded by stopping production to modify the vehicles, and by demonstrating rollovers of six competitive vehicles: the VW Sharon and Golf, Renault Megane Scenic, Peugeot 306, Audi A3, and Opel Astra. Opel rolled a VW and VW rolled an Opel. The methodologies for these demonstrations were not published, and may have used extreme combinations of steering, throttle, and brakes. For this reason the International Standards Organization Technical Committee 22, Subcommittee 9 (Vehicle Roadholding) responded by beginning work on a standardized Elk Test. The result was the introduction of ISO 3888 Part 2

15. In 1997 ATI/Heitz introduced the Heitz Programmable Steering Machine, called "Sprint 1", which could provide precisely-repeatable programmed steering inputs in an easily-installed package.(5) One of these machines was supplied to NHTSA in April 1998.

16. In June 1998 NHTSA began their "Phase II Test Plan for Dynamic Rollover Research", using the Heitz Programmable Steering Machine. The test Plan included eight Protocols: Frequency Response; Variation of steady-state steering gain with increasing lateral acceleration at 50 mph; variation of steady-state gain with speed at constant steer angle; J-turn without pulse braking; J-turn with pulse braking; open-loop Fishhook, without pulse braking, with steer timing determined from the frequency response test; open-loop Fishhook without pulse braking, with steer compensated for the vehicle's steering ratio; and resonant steer testing. The NHTSA protocol attempted to overcome the steer timing problem in the 1972 Michigan tests, but the timing of the pulse braking was still driver-dependent. The test series included 12 vehicles: three each of SUVs, cars, trucks, and vans; in order to define a spectrum of rollover behavior. (6)

17. In 1998 ATI/Heitz implemented "Start at preset speed" and "Roll rate feedback" in the Sprint 1 Machine. The test driver could bring the vehicle to a speed somewhat higher than the test speed, release the throttle and depress the START PROGRAM switch. When the vehicle slowed to the precise set speed the steer program would begin. In this way the uniformity of test initial conditions is enforced. With "Roll rate feedback" the steer reversal in a Fishhook-like maneuver always occurs at maximum roll angle (roll rate zero-crossing), regardless of the vehicle's roll response time. Roll rate feedback offered the simple solution to the "tire/driver learning problem".

18. In 1999 Heitz upgraded the NHTSA machine and supplied a second-generation Sprint 2 machine to several vehicle manufacturers, with the additional test automation capabilities. These features would simplify the test procedure by eliminating the need for prior frequency response testing, and would standardize the timing of steer, regardless of the vehicle dynamics.

19. In April 1999 ATI announced three rollover test protocols: "Reversed Steer With and Without Braking" and "J-Turn With and Without Braking", and “Resonant Steer”. (7) These were made possible by the addition of roll rate feedback to the Steering Machine capabilities. Experience with these protocols and further research led to a number of minor changes in the reversed-steer protocols and dropping the J-turn and resonant steer tests in 2002.

20. A study of the time and energy aspects of rollover testing and the forces on the outrigger led to criteria for data filtering and an objective definition of rollover based on outrigger force. (8) Systematic tip-up testing resulted in criteria for when tires must be changed during a test. Run-to-run comparisons with different steer rates supported the selection of 600 degrees/second as an optimum balance between rollover efficiency and human capabilities, for the ATI test protocol.

21. Reversed-steer testing in 2000 revealed that the "Steady-State Margin" used by ATI and others since 1992 was inadequate, for two reasons. The dynamic roll angles before tip-up were much greater than those measured in the static sidepull tests; and for typical understeer vehicles the reversed steer produced much greater rear tire slip angles and therefore greater total tire forces. Reversed steer produces higher side forces and lower "T/2h", and therefore significantly reduces the "safety margin" from that which had been believed prior to 2001.

22. In October 2002 NHTSA announced its intention to use a Reversed Steer with roll rate feedback as a rollover test for its NCAP Consumer Information Program. All tests will use the Heitz Programmable Steering Machine.

23. Accident investigations indicate that rollovers always involve out-of-control situations. In the most frequently reported scenario a vehicle drifts off the road on the right due to driver inattention causing, in a panic reaction, a gross overcorrection to the left followed by an even greater overcorrection to the right. Rollover occurs during the second half-cycle, or during a following portion of this "driver-induced oscillation". Careful, systematic testing which examines a vehicle's behavior in a steering reversal maneuver, with steer inputs designed to keep the trajectory within reasonable lateral "roadway" boundaries while at the same time observing human factors limits in amplitudes and rates, has relevance to safety evaluation. While the occurrence of tip-up *per se* may be typical of certain classes of vehicle, the broadness of the range of inputs that cause tip-ups may separate vehicles within a class. The reversed steer protocol introduced by ATI is based on these factors.

24. Systematic dynamic rollover testing has demonstrated the inadequacy of steady-state rollover criteria. Rollover occurs when the *dynamic* lateral acceleration exceeds the *dynamic* T/2h by a sufficient amount, for a sufficient time. Dynamic rollover testing using repeatable, reproducible, objective protocols is the only sure way to evaluate

rollover. In particular, it has been found that roll angles in dynamic testing are considerably greater than those in static tests such as side pull or in steady-state testing. This is a very important factor in rollover, since the resulting lateral movement of the vehicle cg causes a dramatic reduction in "T/2h". In fact, the most effective practical measure to increase rollover resistance is a reduction in dynamic roll compliance.

2.5.2 NHTSA vs. ATI Rollover Test

The ATI Reversed Steer Protocol and the NHTSA NCAP Rollover test (variously called "NHTSA Fishhook" or "Road Edge Recovery Maneuver") are similar in that both use reversed steer with roll rate feedback. However, their basic aims are different: the ATI protocol is an engineering test intended to simulate an on-road highway rollover accident while producing data on vehicle characteristics important to rollover. The NHTSA is a Go/No-Go test intended simply to discriminate among vehicles for consumer information. "Relatability" to the real-world highway environment is not as important in the NHTSA test as the ability to discriminate between vehicles in obtaining "Star Ratings" for consumer information.

The standard ATI is run at 50 mph with steer angles incremented from 90 degrees to 270 degrees. 50 mph is a typical highway speed which is vehicle independent, and with steer angles above 270 the loaded "outside" front tire tends to suffer bead unseating. Bead unseating is almost never found in on-road highway accidents, and steer of 270 is considered to "push the limit" of panic steering in non-test situations. (Human capabilities are much greater, and in test situations extreme steer and steer rates are common (12). The ATI test is intended to simulate on-road rollovers, and too-large steer angles may also produce too-large path deviations. With incremented steer, plots can be made of lateral acceleration, yaw velocity, sideslip, roll angle, etc. to study vehicle trending toward rollover. If rollover occurs, the protocol provides small variation in test speed to determine precise thresholds. The protocol also provides optional additional testing at incremented speeds at constant steer to plot motion "partial derivatives" - variation with steer at constant speed and variation with speed at constant steer.

The NHTSA test has regulatory aspects. in which all vehicles from minicars to large vans must be tested under the same conditions For that reason the NHTSA test uses constant steer angle with speed increased incrementally from 35 mph to 50 mph. The lower test speeds are considered safer than 50 mph, especially for the larger vehicles. For fairness between vehicles, the test steer angle is set at 6.5 times the steer required to obtain 0.3g of lateral acceleration at 50 mph. This is intended to compensate for differences between vehicles in steering ratio and understeer gradient. It sometimes occurs that a vehicle will not tip up at the 6.5 ratio due to tire force saturation: in these cases a ratio of 5.5 is tried, sometimes successfully. To avoid bead unseating tubes are used in test tires: this protective measure causes no significant effect on test results.

In NHTSA testing some vehicles exhibit severe bouncing on the outriggers, which is another reason to restrict test speeds. This behavior has not been seen in ATI testing: the difference is possibly due to outrigger design. The NHTSA outriggers are relatively stiff transverse beams attached to front and rear bumper mounts. These can act as undamped springs when a vehicle tips up "hard" onto them. ATI uses one center-mounted outrigger on each side, with air cylinders fitted to soften the strike-down and absorb energy, and they may prevent the severe bouncing experienced by NHTSA. On the other hand, the ATI outriggers permit 4 or 5 degrees of additional roll angle after "outrigger down".

The ATI protocol is limited to tip-ups with the driver on the "low" side, to avoid back injury to the driver when the vehicle "falls" at the end of a tip-up run. The NHTSA test must be run in both directions, which is incentive to limit tip-up roll angles.

2.5.3 The "Hump" Problem In Reversed-Steer Testing (Reference 11)

The use of roll rate feedback, originated by ATI in 1998 was intended as an economical solution to the timing of the steer reversal, since both fast-responding and slow-responding vehicles would have their steer reversals at maximum roll angle. However, in testing during 1991 by NHTSA and ATI of the same vehicle, occasional long steering delays were observed. The problem was traced to variation in the time of zero-crossing of the roll rate signal.

After considerable research at ATI the source of the phenomenon was discovered to be in the difference in roll frequencies of the vehicle sprung mass on its suspension and the total vehicle on its tires. Long delays resulted when the total mass frequency was more than twice the sprung mass frequency. Two "countermeasures" were developed: a bandpass filter to suppress the roll rate signal and a lead network to accentuate it.

The effects of longer delay in steer reversal serves to increase sideslip angles and scrub off speed at a greater rate, and these tend to cancel each other. NHTSA decided to let the vehicle "be itself" and omit the filters. ATI uses band pass selectively: when long delay is observed the test is repeated with a filter and notes whatever difference it makes.

2.5.4 J-Turn Test

The J-Turn test, typically consisting of a 180 degree step steer, applied at 500 degrees/second and held in for several seconds at 50 mph, has been around since the 60's at least. Its advantage is simplicity to run: the steering wheel is manually turned rapidly against a stop. The J-turn has two major disadvantages. If tip-up results, it generally occurs at deviations from the original path of 100 feet or more, And except for an initial transient it is a steady-state test which is an inefficient rollover test. It was dropped by NHTSA because it did not offer anything in addition to theit reversed-steer "Fishhook" test.

In the J-turn with pulse braking, a hard brake pulse is applied at the peak roll angle resulting from the steer input. If all four wheels lock up, the vehicle transitions from a circular path to a straight-line tangent to the circular path, since a sliding tire has no directional sense. Releasing the brakes immediately restores the circular path. By optimizing the brake pulse, the vehicle can be "rocked" at a frequency unattainable with the steering wheel, so tip-up can sometimes be achieved. The brake input must be very precise in timing and must be sufficient to lock the wheels. Its relatability to the rear world is poor at best; and it may not work at all with anti-lockup brakes.

2.5.6 Resonant Steer Tests

On paper the resonant steer test looks promising. However, testing of several protocols by several organizations as part of an ISO task force showed that with large steer angles the resulting trajectories can be "crazy", and repeatability is very poor.

2.5.7 Roll Behavior Near Tip-up Thresholds (Reference 8)

The ATI Reversed Steer Protocol has enabled precise study of roll behavior at the tip-up threshold. Below the threshold the roll angle increases to an asymptotic value or (more usually) a slight overshoot, then settles to a steady-state value. Just above the threshold the roll angle tends to follow an identical trace, but then "takes off" to a high value. At the threshold the roll can go either way, like a card standing on end. In the tip-up case the inflection point where roll angle begins to turn upward can be considered the time of rollover.

In all cases the peak roll angle before tip-up is significantly greater than that found in steady-state tests, because of the time lag between the "excess" roll angle and the take-off point.

REFERENCES

1. R.D. Irvin, P.S. Fancher, L. Segal, *Refinement and Applications of Open-Loop Limit-Maneuver Response Methods*, SAE Paper 730941.
2. *Tire Shoulder Wear In Repetitive Rollover Testing*, ATI Report No. 111901, November 2001.
3. R. Wade Allen et al, *Vehicle Dynamic Stability and Rollover*, Report No. DOT HS 807-956, STI Report No. TR-1268-1, June 1992.
4. *Method for Measuring Lateral Acceleration for Rollover*, Toyota Engineering Standard TSA1544, revised March 1997.
5. E.J. Heitzman and E.F. Heitzman, *A Programmable Steering Machine for Vehicle Handling Tests*, SAE Paper 971057.
6. *An Experimental examination of selected Maneuvers that May Induce On-Road Untripped, Light Vehicle Rollover – Phase II of NHTSA'S 1997-1998*

Vehicle Rollover Research Program, DOT HS Report, July 1999.

7. *Specifications for ATI Rollover Test Protocols,* http://www.atiheitz.com/rolltest.pdf.

8. E.J. Heitzman and E.F. Heitzman, *On Road Rollover Testing: Outrigger Height and Data Filtering,* ATI Report No. 011500, January 2002.

9. Part II, Department of Transportation, NHTSA, 49 CFR Part 575: Consumer Information Regulations; Federal Motor Vehicle Safety Standards; Rollover Resistance; Proposed Rule. *Federal Register, October 7, 2002.*

10. G.J. Forkenbrock and W.R. Garrott, *A Comprehensive Experimental Evaluation of Test Maneuvers That May Induce On-Road, Untripped, Light Vehicle Rollover. Phase IV of NHTSA's Light Vehicle Research Program.* DOT HS 809 513, October 2002.

11. *The Hump in Roll Rate Feedback: Source and Countermeasures, ATI Report No. 030112, January 2002.*

12. G.J. Forkenbrock and D.E. Elasser, *An Assessment of Human Driver Capability.* DOT HS 809 875, June 2005.

2.6 Testing and Consulting Services: Rates and Charges

TRAVEL TIME CHARGES: Travel time charged is based on what seems reasonable under the particular circumstances, including such factors as effective time lost from a normal office workday, work vs. recreational reading or sleep accomplished enroute, and the time "it should have taken" under optimal conditions.

PROJECT EXPENSES: No charges are made for equipment owned by ATI, including test facilities, instrumentation, video, data acquisition and computation equipment; or for normal expendables (videotapes, etc.). Project expenses that are charged as line items include travel expenses, unusual expendable materials, rented equipment, subcontracted work, special printing and reproduction, shipping charges, special fees, or supplemental insurance. Air travel is normally in first class. However, unless specifically agreed otherwise, it is charged at the published unrestricted coach (Y) fare basis, as listed in online reservations systems. Local mileage is charged in accordance with IRS guidelines.

FIXED PRICE SERVICES: When the testing services or the final work product can be sufficiently defined, ATI prefers to quote such services at an agreed-on fixed price, on a "not to exceed" basis.

PAYMENT: Invoices are rendered monthly or at project "milestones", and are due upon receipt. Outstanding balances past due over sixty (60) days are considered to be delinquent. Interest at 1.5 percent per month will be charged on delinquent accounts.

2.7 Statement of Terms and Conditions of Agreement

CONTRACTUAL RELATIONSHIP : Neither ATI nor a prospective Client is bound in any way by a quotation from ATI, except for confidentiality as stated below. ATI assumes that a contractual relationship exists only after a signed agreement equivalent to ATI's Standard Contract Form has been received. If the start of contracted work is delayed by the Client for three months after an agreement is signed, the agreement shall be nullified.

CHARGES: Work performed on a time-and-expenses basis will be charged in accordance with the most current "Schedule of Rates and Charges". Work performed under fixed price purchase of testing services will be charged at, or less than, the agreed "not to exceed" amount. Any unusual types of work not specifically covered by the original agreement may be subject to a revised agreement. A suitable retainer or prepayment will be required from the Client in advance. Such amounts will be held by ATI until the final invoice, at which time the Client's account will be reconciled.

PAYMENT: Invoices are rendered monthly or at project "milestones", and are due upon receipt. Outstanding balances past due over sixty (60) days are considered to be delinquent. ATI, without liability, may withhold delivery of reports and other data, and may suspend performance of its obligations to the Client, pending payment of delinquent charges. Furthermore, ATI reserves the right to decline further work with any Client delinquent in payment of charges due to ATI for previous work, until such balances are paid in full.

EXECUTION OF SCOPE OF SERVICES: ATI will perform all work in accordance with generally accepted professional engineering practice. In the event of deficiencies in the work performed, such as errors, omissions, or ambiguities, ATI's sole responsibility and liability will be to provide without additional charge, corrected, revised, amplified, or clarified data sufficient to correct the deficiency. No other warranty, express or implied, is made concerning work performed under the agreement. ATI will diligently proceed with the contracted work from the agreed-on start date and will report to the Client in a timely manner, except for delays occasioned by factors beyond ATI's control, by factors that were not reasonably foreseeable, or by factors initiated by the Client. Work under the agreement will be terminated upon receipt by ATI of written notice from the Client, except that ATI may complete such analyses, records, and reports as are reasonably necessary to protect professional reputation and to adequately document the work performed through termination. Charges for such work will be kept to a reasonable minimum, not exceeding ten percent (10%) of total charges incurred through the date of termination. Work under the agreement may be terminated by ATI only for just cause, including but not limited to excessive delays caused by the Client.

CONFIDENTIALITY: ATI will hold in strictest confidence all proprietary or confidential information of a Client or prospective Client to which it may be given intentional or accidental access. Unless otherwise expressly agreed in writing, all test data, videotapes, reports, and other information provided to the Client under this agreement shall be the exclusive property of the Client. ATI will not divulge under any circumstances except explicit written direction by the Client any test data resulting from its work, or any aspect of that data including the existence of the test.

MISCELLANEOUS: The Client assumes full and complete responsibility for all uses and/or applications of ATI's work under this agreement, and agrees to indemnify and hold harmless ATI, its officers, directors, employees, or shareholders against any and all liability, damages, losses, claims, demands, actions, causes of action, and costs including attorneys' fees and expenses, resulting from any alleged damages resulting from the aforementioned use, application, or non-use of ATI's work under this agreement. The Client agrees that in no event shall ATI, its officers, directors, employees, or shareholders be liable for any incidental or consequential damages, direct or indirect, arising from ATI's services under this agreement. Unless otherwise expressly agreed in writing, ATI shall retain exclusive rights to all patentable ideas developed during the performance of this agreement. In any litigation involving the Client in which ATI is compelled by subpoena or judicial order to testify at a deposition, or to produce documents regarding work performed by ATI for the Client, the Client agrees to compensate ATI, at its prevailing hourly rates, for all time spent by ATI in responding to such legal process, including all time spent in preparing for and providing such testimony. In such cases the collection of fees billable to opposing counsel will be the responsibility of the Client.

ATI Contract Form

This page last modified on 05/11/2006

3. Chassis Lab Services offered by ATI

3.0 "Topsy" - The Chassis Parameter Measurement Facility

Topsy is a modular system designed for measurement of all composite inertial, kinematic, and compliance parameters that appear in today's sophisticated mathematical simulation models. The emphasis in its design is not "production-line" testing, but research: the operator can observe the vehicle's reaction to developing forces; and as insights develop he can modify the test program as he goes along. Test errors are minimized by running all tests under servo control with continuous display of all data and recording of all known error sources, while the operators closely monitor the test and the developing data. The test facility is organized around an "infrastructure" consisting of baseplates; vehicle locating fixtures; scales; hydraulic and pneumatic power sources; interchangeable valve assemblies and actuators; and transducers. These are organized along with specialized devices into the several forms required for the different tests.

Topsy's development, test methodologies, equipment, and procedures are described in SAE Paper 971056 "Topsy - A Modular Chassis Parameter Measurement System", which was presented at the SAE International Congress in February 1997. An updated description based on that paper is available for download (http://www.atiheitz.com/download.htm).

All measurements made on Topsy are in accord with SAE J 1574/1 "Measurement of Vehicle suspension Parameters for Directional Control Studies - Rationale, Test Equipment, and Procedures", wherever that standard is applicable. In general, measurements on Topsy are extended to higher force levels than those suggested in J1574; and a number of parameters are measured in addition to those covered by that standard.

Topsy uses the ATI/Heitz proprietary data acquisition system, which allows close monitoring of a test in progress, and useful review of completed test programs. All testing is videotaped, with raw transducer data recorded in serial binary form on one or more lines at the top of the picture. Voice, noises, and transducer outputs are recorded in synchronism continuously during the entire test on two-hour tapes, so that anomalies that might occur during or between test runs can later be investigated. Throughout the test, data is displayed as columns of numerics, twelve channels to a column, overlayed on the video picture, for visual monitoring. All processed data is referenced to hours, minutes, and seconds of tape time, so that final plotted data can be looked at while watching a replay of the test run.

The system is designed to use a maximum of nine "data lines" with 12 channels per line, for a total of 108 10-Hz data channels sampled at 60 Hz. However, it is also possible to devote some data lines to "high-speed" use, with two data channels sampled at 480 Hz or one data channel sampled at 960 Hz. A typical test program requires 24 to 36 "low-speed" 10 Hz channels.

3.1 Measurement Services Currently Offered

3.1.1 Inertial Measurements

- Whole vehicle center of gravity
- Whole vehicle moments of inertia: Roll, Pitch, Yaw
- Whole vehicle roll/yaw product
- CG of sprung and unsprung masses separated
- Driveline rotational inertia

3.1.2 Chassis Compliances

Measurements with forces and moments in parallel (aiding) and opposing
Force and moment levels to wheel slip.

Lateral

- Lateral force compliance steer
- Lateral force compliance camber
- Lateral force compliance deflection (X, Y, Z at reference point on spin axis)
- Lateral force y-deflection at tire contact
- Aligning moment compliance steer
- Aligning moment tire twist
- Aligning moment compliance camber
- Roll center height by equilibrium jacking force method

Longitudinal
Forces in parallel, forces opposing, forces applied to single wheel.

- Longitudinal force compliance steer
- Longitudinal force compliance camber
- Longitudinal force caster change
- Longitudinal force compliance deflection (X, Y, Z at reference point on spin axis)
- Anti-dive angles by equilibrium jacking force method

Steering Effort Reaction

- To aligning moment
- To side force
- To balanced thrust/braking
- To unbalanced thrust/braking

3.1.3 Ride/Roll Spring Rates & Kinematics

Measurements from compressed stops to wheel-off
Roll centers can be unrestrained, or fixed at ground or at any height to 3.5 inches below bottom of body.

- Normal forces at wheels
- Ride spring rates
- Ride coulomb friction
- Roll spring rates
- Roll coulomb friction
- Tire spring rates
- Roll stiffness distribution
- Camber change
- Caster change
- Swing arm lengths
- Ride steer
- Roll steer
- X,Y,Z displacements of reference point on spin axis
- X,Y displacements of tire contact
- Roll center heights by displacement method
- Shock absorber travel

3.1.4 Steering System

Measured Lock-to Lock

- Wheel steer vs handwheel angle
- Overall steering ratio vs handwheel angle
- Ackerman error
- Camber angle
- Caster change
- Caster angle
- Steering axis inclination angle
- X,Y,Z displacements of reference point on spin axis

3.2 Measurement Methodologies

Inertial Measurements

Vehicle is locked to baseplate Frame. For CG measurements Frame is mounted on knife edges, and is cycled through tilt angles by a vertical linear actuator, equipped with a load cell and mounted on a torque arm. CG is normally measured at several ride heights, to permit CG estimation under different loadings. For roll and pitch inertia Frame is mounted on knife edges and linear springs. For yaw inertia Frame sits on "yaw cradle", which is attached to the floor through a large-diameter ball bearing with torsion bar spring restraint. Separation of sprung and unsprung masses by measurement of total vehicle CG height at several different ride heights is theoretically simple. However, because of body beaming deflection and the compliance of engine/suspension subframe rubber mounts, the results have been so far insufficiently accurate. Development of the methodology is continuing.

Chassis Compliance

Vehicle sprung mass is locked to the Frame, with tires on ball-bearing low-friction tables mounted on platform scales. Hydraulic servo cylinders equipped with load cells apply forces and moments at the tire contact patches. Compliances are measured from a transducer plate mounted on lugnut extensions to a ball-slide follower mechanism attached to the sprung mass, or from the tire contact surface to the Frame.

Ride/Roll Spring Rates and Kinematics

Vehicle rests on scales and ball bearing tables. Sprung mass is restrained laterally and fore/aft by vertical posts in linear ball bearings. Four hydraulic servo cylinders apply ride and roll forces. Vertical posts are unrestrained vertically for ride motions. For roll motions they can be left unrestrained so vehicle "finds its own" roll center; or they can be locked to define roll centers at ground level or at any level from 4 inches below ground to 3.5 inches below the sprung mass bottom of body. Deflections are measured from a transducer plate mounted on lugnut extensions to a ball-slide follower mechanism attached to the sprung mass, or from the tire contact surface to the Frame.

Steering

Vehicle rests on scales with ball bearing tables, restrained by unlocked vertical posts. The steering wheel is cycled slowly by hand or by geared electric motor through full lock. Measurements of displacements of reference point on the spin axis are made from a transducer plate mounted on lugnut extensions to a four-axis ball slide assembly (X,Y,Z, steer angle) attached to the sprung mass. Caster and steering axis inclination are computed from camber and caster changes.

3.3 Specification of Kinematics and Compliance Tests

3.3.1 Standard Conditions

All tests are run at, or referenced to, curb trim height. All kinematics tests are run with engine stopped. Steering system tests are run with engine running and with engine stopped. Only handwheel torque is plotted for the engine stopped condition, as explained in the Notes below. Front lateral force and aligning torque compliances with forces or torques adding are run with engine running; and with forces and torques opposing the engine is stopped; as explained in the Notes below. Front longitudinal force compliance tests are run with engine running. All rear compliance tests are run with engine stopped.

3.3.2 Equations Fitted to Plotted Data

Third-order least-squares polynomial equations are fitted to most data plots. Where dictated by the character of the data, three-element linear plots (thru-center, and positive and negative extremes) are used instead. Examples of the latter are steer tests, where roadwheel steer angle vs aligning torque usually shows a distinct difference between on-center and off-center slopes; and wheel loads in ride and roll, where rates change as bump or rebound stops are engaged.

3.3.3 Choice of Data to Be Plotted

Raw data (vs time) required for all plots will be supplied on floppy disks for all tests, and will be included in the test charge. All of the plots in the following listing can be generated from the floppy disk format. Since many of the data plots in the listing are useful only in some simulation models, and the quotation for Data Processing includes a separate charge for each plot, costs will be minimized by circling only those plots actually intended for use, or those for which fitted equations are desired.

3.3.4 Organization of Data Plots

Data plots are organized into four groups:

```
Test type and configuration
    Non-standard test conditions if present
        Test
                Parameter plotted
```

Examples of non-standard test conditions are engine running or stopped, non-curb ride heights, etc. For example, a front compliance test at 30 mm jounce instead of curb height would be coded as FC-30J-SFA, etc.

Notes:

1. In front steering and compliance tests, side forces adding and aligning torques adding include steering column compliance, which can be significant with power steering inoperative because the engine is stopped. With power steering in operation the steering column is affected only by steering wheel effort. Forces and moments opposing will tend to balance at the steering gear, and so do not load the steering column.

2. The self-centering effect of front end geometry is best evaluated with power steering inoperative.

3.4 Quotations

Quotations are based upon the following components of cost:

1. Incoming vehicle inspection: listing of vehicle specifications, departures from manufacturer's specifications, dimensional measurements, topping up or draining gas tank, cleaning of underside of accumulated dirt, preliminary vehicle wheel weights, etc.
2. Mounting and centering of vehicle on test fixture.
3. Ballasting of vehicle, if necessary.
4. Installation of vehicle clamping devices, or of Ride/Roll actuators and scales.
5. Setting and recording installed ride height per test specification.
6. Calibration of equipment and instrumentation.
7. Installation of special equipment and instrumentation appropriate to each test.
8. Performance of the test.
9. Data Processing.
10. Plotting of data.
11. Preparation of report.
12. Removal and restoration of the test vehicle to as-received condition.
13. Post-test calibration checks and restocking of instrumentation. and equipment.

Whole-car CG and Moments of Inertia
Whole-car center of gravity and moments of inertia are all measured with a single vehicle setup on the testing Frame. The principal cost items are 1 through 7 above. Current (March 1996) approximate quotations are: $2000 for CG height at specified trim and two additional trim heights or loading conditions; $500 each for roll, pitch, and yaw moments of inertia. For litigation-involved projects, we can provide as an extra-cost option, an on-camera, stepwise multipoint calibration of each measuring system, with computed linearity, measuring tolerance, and confidence limits for the particular test.

Kinematics and Compliance Testing
Compliance tests done alone might be done with hydraulic, electric or manual actuators in the vehicle positioning system, with hydraulic servoactuators used to generate tire side forces and aligning torques. Kinematics testing requires hydraulic servoactuators for body jounce, pitch, and roll motions. When Kinematics and Compliance tests are both to be run, the same setup of hydraulic actuators in the Ride/Roll crossmember fixtures is used for both tests, with useful cost savings. Items to be measured are selected from the list of identification codes. Of these, items to be plotted and those to be curve-fitted are selected, and a quotation is made based on all of these considerations.

As noted under "Specification of Kinematics and Compliance Tests", raw data for all items measured are supplied on floppy disks. Some costs can be saved by plotting only items certain to be needed: others can be plotted by the Customer or by HCL at any time later.

Time & Material Quotes
For exploratory "cut & try" tests with a customer's engineer present, a quotation can be prepared with a fixed price covering defined items, with time & materials for "messing around" negotiated separately.

3.5 Rates and Charges

Fixed Price Services
When the testing services required or the character of the final work product are sufficiently defined, ATI prefers to provide such services at an agreed-upon quoted price, on a "not to exceed" basis.

Equipment Used
The use of equipment owned by HCL, including test facilities, instrumentation, data acquisition, video, and computation equipment, is included in the rates quoted above, or in fixed-price quotes.

Other Project Expenses
Project expenses that are included in time & material charges as line items, at HCL's cost, include (but are not necessarily limited to) subcontracted work, special printing and reproduction, and shipping charges.

3.8 Terms and Conditions of Agreement

Same as Section 2.7.

last modified 05/11/2006

HEITZ SPRINT 3 PROGRAMMABLE STEERING MACHINE

FEATURES

Powerful, Fast, And Accurate
16 programs of 16,384 steps in each plug-in EPROM
Basic tool for NHTSA rollover & ESC research
In use by research groups in USA, Japan, and Europe
Roll Rate Feedback and Start Program at Preset Speed functions
Thumbwheel switch selection of program, max steer, start speed, direction of initial turn
EPROMs programmable from notebook computer
Flash memory card option (all machines retrofit expected 2006)
Optional capability to follow an external analog steer angle input
Alternative "on the fly" computer control via USB interface (expected in 2006)
Machine clamps to vehicle handwheel for 15-minute installation
Alternative installation directly to steering column
Handwheel panel meters show speed and steer angle
Analog outputs for steer angle and torque
Driver’s hands remain on Sprint handwheel throughout a maneuver, for safety
Releasing either of two handwheel switches reverts to manual control
Powered by its own batteries with charge maintained from vehicle
Installed weight: Machine 13 kg; Battery/Electronics Box 15 kg.
Two transit cases for storage/transport
3-year full warranty

COMPONENTS

The photo above shows all components for the Sprint application. The B/E (Battery/Electronics) box is a rugged ABS case in which the cover is removed for installation. The B/E Box is connected to the vehicle 12-volt system, the Steering Machine, the Command Module, and the data acquisition system by the four cables shown. The Grounding Plate (a "disk brake rotor") attaches to the vehicle windshield by adjustable struts and suction cups. The Steering Machine clamps to the vehicle handwheel using the 4 mm hex driver tool. The EPROM is inserted in the ZIF (zero insertion force) socket on the leftmost PC board in the B/E Box. A second EPROM is available for optional control of throttle, brakes, recorders, or other devices. The Command Module contains digital thumbwheel switches for selection of program number, direction of first turn, maximum programmed steer angle, and vehicle speed for program start.

OPERATION

With the system unenergized a failsafe brake locks the motor and the Handwheel is ungrounded, so driving is normal. The driver energizes the system by depressing the right-hand thumb switch. After a short self-check cycle the motor fail-safe brake is released. Since there is as yet no Program signal, the servo holds the angle between the vehicle steering wheel and the Sprint Handwheel to zero, and driving remains normal. With energization one of the two green "Klutzlights" will indicate the direction of the initial programmed turn for drivers with poor short-term memories. When the driver depresses the left-hand thumb switch the Program is enabled and the grounding brake is applied, freezing the position of the Sprint Handwheel. If "start at speed" is not selected the program starts immediately; with "Start at Speed" the Program will begin when the vehicle has slowed to the preselected speed.

SAFETY

If the left-hand switch is released, the Program is inhibited and the Grounding Plate is freed. The servo holds the last commanded steer angle between vehicle and Sprint handwheels, with manual control. With release of the right-hand switch, the system is de-energized: the Grounding Plate is freed and the motor fail-safe brake locks the motor position, restoring full manual control. Releasing either or both switches produces the same driving condition.

The Sprint Steering Machine is capable of very large steer angles, at rotational speeds over 1000 degrees/second. For this reason it is important from a human factors standpoint that the driver's hands remain on the handwheel in the same way for both normal driving and programmed conditions. This feature is made possible by use of a "Series Servo", in which the Machine adds to the rotation of the Sprint Handwheel. During programmed steer the vehicle steering wheel rotates while the Sprint handwheel remained "grounded" to the vehicle windshield. During violent maneuvers the driver's hands remain on the stationary Sprint handwheel, for body support and machine control. In our competition's steering robots, the handwheel spins: in violent maneuvers the driver must avoid contact with the spinning handwheel while "hanging on" to a joystick.

SPRINT 3 SPECIFICATIONS

INTERMITTENT DUTY TORQUE, at any speed to 1500 degrees/second:
Peak torque (adjusted by a current limiting resistor) = 60 Nm. (80 Nm on request).
Peak torque for a 2.7 second burst followed by power amplifier foldback to a resistor-adjusted 25 Nm.
Amplifier controls peak duration to maintain long-term average current at continuous rating.

CONTINUOUS DUTY TORQUE, at any speed to 2000 degrees/second:
25 Nm average or RMS. (Peak torque for continuous sinusoidal operation = 30 Nm).

TORQUE MEASUREMENT
To 100 Nm at 1.5 percent linearity, no damage limit.

ANGLE MEASUREMENT
Resolution 0.025 degrees, 16-bit D/A, Full-scale switchable 800/400/200/100 degrees and additional potentiometer-adjustable gain for flexible scaling.

INSTALLATION
Machine clamps to vehicle steering wheel. Left/right are synchronous for automatic centering. Upper/lower are independently adjustable, since steering wheel center is frequently offset vertically from the center of steering column. Adjustable-length struts (11 to 25 inches, 280 to 640 mm) and oval-shape (3 x 6 inches, 75 x 155 mm) suction cups ground Handwheel to windshield. Adapters are supplied for mounting directly on the steering column.

Battery/Electronics Box has cables to vehicle battery, to hand-held Command Module, to Steering Machine, and to data system (Speed & Roll Rate in; Angle & Torque out).

"Hand-held" Command Module sets program, steer angle, direction, and start speed by "pushwheel" digital switches. It connects to Battery/Electronics Box through 15-pin D-Sub cable. It is usually taped down somewhere within the driver's reach.

SIZE & WEIGHT
Machine has 15 inch (380 mm) outside diameter handwheel. Handwheel to vehicle steering wheel is 5.2 inches (134 mm). Installed mass is 29 pounds (13.2 kg).

The Battery/Electronics Box measures 14 x 10.5 x 6 inches (360 x 270 x 160 mm) and weighs 33 pounds (15 kg) installed.

The Command Module measures 4.7 x 2.6 x 2.0 inches (120 x 65 x 50 mm) and weighs 11 oz (0.310 kg).

POWER
Input power is 9 to 18 volts from the vehicle's battery/alternator, which is used to maintain a 13.6 volt charge on system batteries through isolating regulated DC/DC converters. System has five 12-volt, 5 amp-hour lead-acid batteries connected in series for 60 volts at the power amplifier when the servo is energized; and an additional 12 volt, 5 amp-hour battery for miscellaneous system use.
With the system energized, the maximum current draw from the vehicle is 8 amps since additional current is supplied by the batteries.
The DC-DC converters isolate the system from the vehicle battery/alternator system, to prevent accidental ground loops.
The system is protected from reversed connection and alternator load dump transients.

WARRANTY
Heitz Automotive Testing, Inc. warrants the machine and its components to be free from defects in materials and workmanship at the time of manufacture, and to operate normally for a period of three years from the date of delivery. This warranty is subject to the following qualifications:

(1) The machine must be used normally. Heitz Automotive Testing cannot be responsible for machines subjected to severe physical or electrical abuse, or damaged by gross negligence or by vehicular accident, or crash-test collision or rollover.

(2) Certain "programming rules" must be observed, as described in the Technical Manual under "Programming Rules for Motor Heating Considerations" in Section 4 and "Motor Heating Considerations" in Section 6. For example: no program should hold the machine stalled at full current for an extended period.

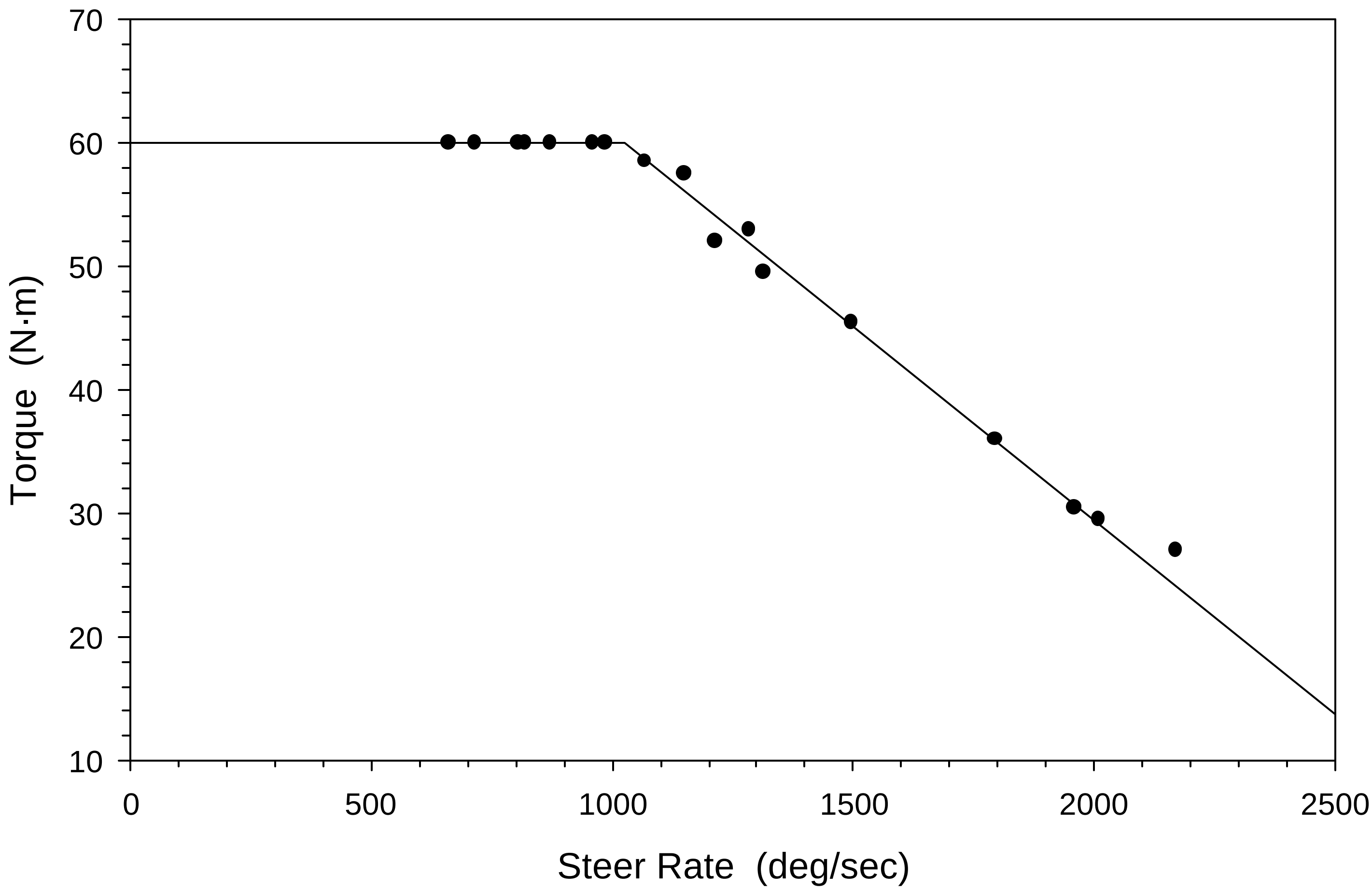
According to customer's preference, we will immediately and at no charge FedEx any required repair parts, or we will repair and return within 7 days a machine sent to us for repair. Although there will be no charge for repairs, if a machine is returned the customer may be asked to arrange for and pay for shipping charges.

FURTHER INFORMATION
For further information contact:

Heitz Automotive Testing Inc.
6 Moores Mill Road
Pennington, NJ 08534 USA

Telephone: +1 609-466-2071
Fax: +1 609-466-4866
Email: ed@atiheitz.com

Figure 1
Max Torque vs Steer Rate
measured using step inputs of 360 or 720 deg on Sprint 3 S/N 3-14



ATI / Heitz Download Page

The following documents are available in Adobe Acrobat Portable Document Format (PDF). To be viewed or printed, these PDF files require an Acrobat viewer, such as Acrobat Reader or Acrobat Exchange. Acrobat Reader is available free of charge for Windows, Macintosh, SGI, Sun SPARC, DOS, and HP platforms. Click on the button below to get Acrobat Reader from Adobe's website.

Download Report - "Topsy - A Modular Chassis Parameter Measurement System" (topsy.pdf - 03/01/97 - 838K)

Download Report - "A Programmable Steering Machine for Vehicle Handling Tests" (progstr.pdf - 03/01/97- 547K)

Download Specifications for the ATI Rollover Test Protocols (rolltest.pdf - 05/20/02 - 188K)

Download Report - The Hump in Roll Rate Feedback: Source and Countermeasures (Hump.pdf - 551K)

Download Report - Tire Shoulder Wear in Repetitive Rollover Testing (TireWear.pdf - 885K)

Download Report - On-Road Rollover Testing: Outrigger Height and Data Filtering (LAR_filter.pdf - 321K)

Download Report - The Design of ATI's Outriggers (Outrigger.pdf - 3098K)

Download Full Text of this website not including documents on this page (atiheitz.pdf - 05/11/06 - 316K)

Steering Machine Documentation and Tech Notes

Sprint 3 brochure (Sp3_Brochure.pdf - 194K)

Sprint 3 Operating Manual (Sprint3_Operating_Manual.pdf - 816K)

Sprint 1/2/3 Programming Guide - Sprint3 Tech manual section 4 (SprintProgGuide.pdf - 83K)

Sprint 3 Test Control User Guide (TestControlUserGuide-sp3.pdf - 213K)

Stock EPROMs for NCAP Testing: Heitz Tech Memo 30213 (NCAP_EPROMs.pdf - 10K)

ROMsteer test program files

NCAP test programs as described in Tech Note 30213 above: (rs_ncap.zip - 12K)

Windows Software

Download RomSteer Programming software for Steering Machine here: http://www.atiheitz.com/Romstr.html
(Link opens page that includes software and installation instructions)

Download Needham's EMP-11 programmer software here:
http://www.needhams.com/downloads/empw1_6.exe
(This is a direct link to the EMP-11 software installation program file on Needham's website)

This page last modified 05/11/2006