SAE Fatigue Design and Evaluation Committee Meeting
Micro Minutes
October 11 & 12, 2000
Urbana, IL
Host: Darrell Socie - SOMAT Corporation

Disclaimer: These are not the official minutes. They are just one individual's notes.

Date and the location of the next meeting: April 3 & 4, 2001, Detroit, Michigan

Wednesday, October 11, 2000

Main Committee Meeting: Phil Dindinger called the meeting to order. Phil announced that Arlene Catrett has replaced Phyllis Roessler as our SAE Staff representative. Any questions about SAE's policy of no paper meeting announcements may be addressed to Arlene at 248-273-2494 or by email at acatrett@sae.org. The Surface Enhancement Division has cancelled their session for this meeting because of conflicting dates.

Local Arrangements: Darrell Socie welcomed us to the University of Illinois. He mentioned that the campus was about one mile from the meeting room, but this was as close as the available parking on campus. Darrell acknowledged Peter Kurath as the organizer of the technical session.

Fatigue Concepts in Design Short Course and ASTM - Ralph Stephens announced they have conducted the SAE FD&E -University of Iowa Short Course in Fatigue since 1972. Next year will mark the 30th session with a total of some 3000 engineers participating. The vast majority signed up for the course because of "word of mouth" advertising. This year attendance was about 80 people, which is right near the break-even point for expenses. Next year the course will be held in the Chicago O'Hare airport vicinity in November. Steve Haeg has replaced Gail Leese on the short course faculty. Ralph announced the upcoming ASTM E08 committee meeting on Fatigue and Fracture will be held in Orlando the week before Thanksgiving. The ASTM has recently named Darrell Socie a "Fellow" for his work in fatigue.

H. O. Fuchs Award - Rebecca Kaufman from the University of Waterloo, discussed "Fatigue Testing of Sheet Metal Subjected to Uniaxial Tension/Compression." Her objective was to fabricate and test sheet metal without buckling for large strain amplitudes. She tested single thickness and laminated specimens with double and triple layers for both 5754 aluminum and automotive body IF sheet steel. The laminating technique was to cut rectangular specimens, clean, coat with 24 hour curing epoxy, clamp together with spring clamps and heat at 150o C for one hour. Then the final shape was cut on an NC machine. Samples were tested with an antibuckling guide attached with Teflon coated screws. They obtained strain life curves for single thickness, double and triple laminated samples, with lives between buckling and 107 reversals. Results for

5754 aluminum and for the steel samples fell into one nice curve for each material. Maximum strain achieved for the double thickness specimen was about double that for the single thickness specimens. Results will be published at the March 2001 SAE Congress.

Structural Analysis Division
Dan Lingenfelser (substituting for Zheng Xian Bai and Mary Wickham) opened the session and the minutes were approved. Dan showed a slide of the notes from the April planning session to be discussed on Thursday. Jeff Sundermeyer from Caterpillar Inc. Product and Process Simulation Group discussed "Ground Load Interface in Dozer Blades." Their goal is to construct the time varying free body diagrams of the blade to build a loads database for finite element analysis. Loads are partitioned into three groups: measured loads, static determinate unknown loads, and unknown remaining loads. They derive an equation that looks like ? = A f, and apply a least squares estimate to derive an A matrix. Note that constraints of six degrees of freedom at one node may cause numerical problems. Arbitrary loads can be approximated as a linear superposition of forces. Their program picks the best locations for strain gages by maximizing a determinant. They iterate to a solution by adding more strain gages until the variation multiplier drops off. The variation multiplier drops off by a factor of 10 for optimum gage locations. They had to watch for multiple colinearity by cross plotting recalculated values versus measured strains and compared to results from previously tested blades. Future work includes a new blade test under vibrating conditions and applying a frequency response analysis. Question: What type of gages were used? Answer: Single gages at each location. The program specified the angle. Question : Why were all of the optimum gages in one area? Answer: Related to the degree of repetition. Mary Wickham also found clusters.

Mark Barkey from University of Alabama presented " Spotweld Fatigue Under Multiaxial Loading" This project was sponsored by Daimler Chrysler (Dr. Yung Lee). Mark used an MTS uniaxial test machine and actuators. Resistance spotwelds are the primary welding process on most automobiles, with approximately 3000 to 5000 spotwelds per vehicle. Previous work was done in plane shear or cross tension samples. The objective of this test was to determine fatigue life under combined loading. A test fixture was designed at Chrysler to apply loads through the weld nugget at angles off the plane of the nugget of 0o 30o 50o and 90o. Tests were run on Galvannealed sheet steel with nugget diameters of 5.4mm and 8.0mm. Failure modes depended on load levels and loading angle. Higher loads meant more tear out. Cross tension loads caused a pull out of the spotweld in the circle of the weld. Calculated fatigue lives were based on Swellen and Lo (?) Sheppard, and Rupp methods. They have a database of more that 150 spotweld
fatigue tests. Results indicate combined loading was more severe than single axis loading.
Question: Combined loading? Answer : More of proportional nature.

Component Test Division
Raj Thakker opened the session and the minutes were approved. Raj noted this is his last meeting as division chairman. Paul Lubinski is the new

chairman of the Component Test Division. A candidate for vice chairman is needed.

Ric Mousseau from the University of Toledo reported on the progress of his work on "ATV Dynamic Modeling Simulation." This model is posted on the website at
http://www-mime.eng.utoledo.edu/people/faculty/rmoussea/Atv/ATV.html
Included are zipped files of an executable file, and input file, and a plotting code Winep. The input file is for a 3m long by .1m high trapezoidal bump on the left side. Bump.erd is a header file, and Bump.bin is a binary data file. Double click on Bump.erd to start the Winep. You can change "binary" to "text" to generate a text file to be read by Excel. We need to look at the parameter sets, evaluate the model and compare to the measured test data from Ali Fatemi, Will Mars and Defiance. The model is intended as a simple easy to use dynamics model to predict ATV durability loads, and as a supplement to ADAMS and DADS dynamics models. The code uses Autosim, a multi-body simulation code to create a fully parametric model that creates an effective simulation that runs in Windows computers. MSC (?) has allowed the distribution of the ATV Model to FD&E members. Basic assumptions are this is a rigid body model, original bushings are revolute joints, the tire model is a linear force in the vertical direction, and there are 9 degrees of freedom. Input vehicle speed is constant, and there are right and left hand road profiles, similar to a four-poster test. Since Autosim was written for handling simulations, we need to write some software to get a complete force set. (Grad student project.) Other loose ends: Add steering system, improve tire model (1)lookup table, (2) Cooper measured tire data (Will Mars), (3) Improve enveloping tire model and (4) account for dynamics of driver .

Tom Renner from MTS Systems discussed "Emperical Dynamic Models of Non-Lionear Suspension Components" Emperical Dynamic Models (EDM) is a blackbox, neural network solution to a wide variety of systems with random inputs, multiple inputs and outputs such as bushings, tires and shock absorbers. We can create models faster than with other analytical methods, more accurately and with faster execution times. The process is to excite the system using random signal inputs, calibrate the model versus existing data and against a user database, then to use the model by itself or in a larger dynamics model like ADAMS. The shock absorber model is a linear model that uses FRF to handle hysteresis and a polynomial function to handle non-linearities. The bushing model uses triaxial test machine data, and handles cross coupling of loads. The tire model requires three input channels; one radial deflection, slip angle, and camber. Measured data compared to predicted lateral forces compare within 5%. Summary: we can generate Emperical Dynamic Models faster, that are self validating, and more accurate than with other black box methods. Limitations: Applications need to be within the region that generated the models.

Jude Restis from Fatigue Technology Inc. discussed " Fatigue Life Enhancement of Holes Using Cold Expansion" application is widely used in aerospace application of pulling a ball end mandrel through a split sleeve bushing placed inside a hole to create compressive residual stresses approximately equal to compressive yield strength at the edges

of the hole to effectively increase damage tolerance and fatigue life. They use Patran and Abaqus with nonlinear solutions for their analytical work. The method is most effective with high interference fasteners. Air Force tests show improvement in fatigue life of three to one up to ten to one. There are not many aircraft that do not use this technology. The method is now applied in rail bridges, and medical implants, and for example on one ferry window stop drilled holes through fatigue cracks for repair. Summary: Benefits of cold expansion applications include improved fatigue life, retarded fatigue crack growth, enhanced existing structures, and the process is not dependent on operator.
Question: Fully reversed loading applications? Answer: Showed only small improvements.

Ric Liest from Cessna Aircraft discussed his approach to "Analysis of Lug Holes with Interference Fit Bushings." Ric tried to match finite element analysis of lug holes with interference fits to test results by tailoring interference. His analyst referred to an Army test report on "Fatigue of Lugs containing Liners", USAAV Tech. Report 70-499 by May, Ajak and Maloney, 1972. Ric discussed a specific dual slope loading and unloading curve. Ric asked for comments on this approach.

Fatigue Life Prediction Division - Chin Chan Chu opened the meeting and the minutes were approved.

Helmut Dannbauer from Magna Engineering Center, Steyr, discussed " A Stress Based Fatigue Prediction Concept and It's Application to Vehicle Components." Operating strengths are affected by materials, shape, production methods, stress surrounding mediums and temperatures. Components may have different S/N curves for each location. His approach is a stress based concept because his analysts typically work with linear analysis and stresses. He uses a Kt"free" fracture assessment with a relative stress gradient, considers local plastic effects, which is less sensitive to input errors and produces fast and reliable results. The type of loading is a notch superposition and he compared finite element results to test results.

Vladimir Ogarevic from nCode International, discussed "Thermal Fatigue of Automotive Components." This work was from a project with Ford Motor Co. on thermomechanical fatigue (TMF) of exhaust manifolds. They interpolated S/N curves at various temperatures. For higher temperatures oxidation and creep effect were not 100% reversible because of grain boundary relaxation. Layers break down after repeated cycles until rupture. Interactions between different failure mechanisms are crucial. Thermomechanical fatigue analysis based on isothermal approach are shown in the literature. In general these methods are fuzzy interpolation models. This TMF method involves a simplified stress strain and visco plastic analysis. Strain based methods are used in the U.S. (Manson-Coffin for low cycle fatigue, and uncoupled stress based methods are used in Europe. Strain based LCF methods are expanded to include time and temperature effects. Failure behavior with large strains involve cycle extrapolations. There are relatively few test results reported in the literature for low temperatures and time dependencies. Tests need to be run for specific high temperature and time dependencies, duplicating service conditions. The end result is a

"design Curve" for every different cycle (temperature and time dependent.)
Correlation with experimental results are within a factor of 2-3x life. A "Schitoglu" (?) method uses both stress strain and damage models and a treatment for creep. For some problems visco plastic FEA solutions work well with Abaqus and Ansys. Validation of the "Chaboche" model is imperative.

Will Mars from the University of Toledo and Cooper Tire, discussed " Cracking Energy Density As A Fatigue Life Parameter for Rubber Subjected To Multiaxial Conditions." Will claimed to have some exciting results to show that may apply to non-rubber materials. His method is based on fracture mechanics and energy release rates. Strain components don't reach peaks at the same time. Energy release rate is the product of stress tensor times strain. CED provides a life approach based on fracture mechanics. CED is equal to SED for simple tension. Need to validate for variable amplitude loading.

Road Load Data Acquisition Division
Ray Thompson opened the session and the minutes were approved. Mark Early
for John Deere Technical Center discussed his work with Gary Mauritizson on "ATV Road Load Data Acquisition." Instrumentation included wheel force transducer made by Mike Messman at John Deere, 3 forces and speed at all four wheels, 3 triax accels, 3 vertical accels on the racks, steering angle, displacement of shock absorber with a string pot. 8 uniaxial strain gages based on field (Sundown) locations, a bending bridge on the handlebars, load washers on the foot pegs, and load cells under the seat. A total of 58 channels were recorded on two Somat eDAQ units. Data acquisition: Data was recorded over mild bumps Sundown ski area, discrete wood bumps, two severe bumps (steel on concrete), really severe bumps, a concrete twist ditch at John Deere Waterloo, measured road profile at John Deere Waterloo, and severe road profiles at Sundown. Raw data and road profiles are available on the website in Excel format. Raw data still needs to be corrected for drift, filtered, long events and turns edited out, and the runs separated. Rotating loads need to be converted to stationary reference wheel loads.

Chakrapni Vallurupani , from Mechanical Dynamics Inc., discussed " Functional Virtual Prototyping in the Fatigue Design and Evaluation Process." The challenge of the functional virtual prototype is to capture
the service environment and get the inputs into the vehicle, like spindle loads into component loads. Historical wheel force transducer loads were classified into input loads into FEA models to provide a simple characteristic but non predicted loads. Measured WFT loads require physical prototype. ADAMS offers a functional digital car. Their five phase process includes: 1) Build 2) Test 3) Validate 4) Refine and 5) Automation. Build is accomplished using a library of auto components (bushings, springs, and damper data) and integrating controls, 3D CAD and hydraulics. They have developed dynamic models of MTS systems. Durability schedule events include schedule composition, random events (Belgian blocks), transient events (potholes), and quasi-static events (twist ditches). Calculated damage has been shown within a factor of

two. Components needing refinement include tires, shocks, bushings, and structures. Ask what does a change in parameters mean? For instance flexible frame influence on twist events? Automation means defining templates. Information can be leveraged off handling type models. Functional Virtual Prototyping results and animations have been used in heavy truck, valve train, entertainment, aerospace and automotive applications.

Ray Thompson read some comments from Christoph Lesser on the fatigue.org website." Christoph is looking for comments, suggestions, and volunteers. Is the fatigue.org website redundant or complementary? It seems to be faster and easier to input info and data into fatigue.org website. Currently, there is lots of info and data posted, but not much "Knowledge" and progress. We need volunteers to turn data into useful information. Should we pay someone (students?) to do this? Email comments and replies to Christoph at chrisleser@mts.com.

Material Properties Division John Bonnen opened the session and the minutes were approved. John awarded Material Properties Division database awards ("Brewskis") to Phil Dindinger, Ralph Stephens, Russ Chernenkoff, Mike Mitchell, Keshevan/Topper, and to a sixth anonymously , submitting data sets to the public domain on

http://fde.uwaterloo.ca/Fde .

John read a brief report from Russ Chernenkoff on ATV weld microstructure.

Allan Kallmeyer from the Un. of North Dakota reported on progress of the Composites Task Group. Alan and Peter Kurath have been working with nylon 66 reinforced with random glass fibers 250 microns long by 13 microns in diameter. The test plaques were supplied by Dupont, and more are available for test. Test material was shipped in sealed containers. They cut dog bone shaped test samples 170mm by 25mm, with minimum width of 15mm 30mm long and with 20 mm corner radii. They tested various stress ratios, frequencies and temperatures. They also tested premolded tensile bars under monotonic loading under strain rates of .0002, .001, and .005 in/in/sec. Results showed some small effects on tensile behavior.

Ralph Stephens from U. of Iowa reported on a project on "High Mean Stress Effects" which will be a master's thesis for two grad students at the U. of Iowa. They will be testing three versions of SAE 1045 steel at hardness of Rc10, Rc40 and Rc54, with notched and smooth specimens. They will obtain S/N or ?/N life diagrams for lives of 102 to 5 x106 cycles and compare with SWT, Morrow, Goodman, Haigh, Fuchs, and other models, and provide SEM fractography, creep relaxation models, and additional literature reviews. Ralph is interested in comments and help machining test specimens.

Rebecca Kaufman from the University of Waterloo, discussed "Mean Stress effects in Multiaxial Fatigue." Her experiments were on the effects of tensile and compressive mean stress on biaxial tube specimens subjected to shear loading. For pure shear loading surface aspherities contact each other, where a tensile load opens the crack faces and decreases fatigue life. Compression forces the fracture surfaces together and increases fatigue life. John Bonnen found a factor of two reduction in fatigue lives for periodic overloads. They chose a Fatemi and Socie model. They designed a new test specimen with the aid of finite element analysis, applied internal and external strain gages. Results for the axial and radial directions were within 5% of the FEA results. They showed no increase in fatigue life for □ɸ mean stress, and a great increase in fatigue life for -300 Mpa mean stress. Conclusion was there is a linear relation between applied mean stress and alternating shear stress.

Daniel Kujawski, Western Michigan University, reported on "A Modified Partial Crack Closure Model." They investigated the effects of R ratio on crack growth rates. Elber defined an effective ?K as the difference between Kmax and Kop thirty years ago. They added a funcion g: Keff = C - Kop [(1□1)g], where g is a transition function. Their results compared to experiments by Paris, showed dramatic improvements in correlation at threshold levels. Conclusions: Modified partial closure model correctly predicts R ratio effects for investigated alloys.

Technical Session, Thursday October 12, 2000
Organized by Peter Kurath, U. of Illinois

Peter Kurath, U. of Illinois, reported on "Implications of Testing Solid Bars for Axial Torsion Loading." Previous work has said we need thin walled tubes for test samples. It is difficult to make some of the exotic alloys into thin wall specimens. If the loading is totally elastic it may not matter, but there may be problems if plasticity is involved. They used a finite difference model and Taylor expansion for first and second derivatives to look at proportional loading with axial and torsional shear loads, assuming constant volume and ?=0.5. When you look at axial stress vs. shear stress it's not quite proportional. Compressive stresses at surface are slightly lower then at the corners. They looked at tubular specimens for surface strains similar for proportional loading. Through tube there was almost no gradient, similar to a constant stress through the wall thickness. For solid bar loading (12mm diameter) there was some effect from out of phase loading, due to out of phase hardening. In stress control, the "box" path turned into a 'diamond path." with axial stresses higher at the end points and a higher effective stress at the center of the bar because of redistribution of the load. Radial stress goes to zero at outer surface, and may not be zero at the center. For big tubes they got same axial stress/shear stress as for solid bars. Triangular loading path produces some ratcheting, but solid shaft is similar to tubing. Conclusion: Surface stress and strain are not highly altered between solid and tubular sections. Maybe we shouldn't spend the extra money to machine tubular specimens.

Allan Kallmeyer from the Un. of North Dakota reported on student Ahmo Krgo's "Multiaxial Fatigue Life Predictions for Ti-6Al-4V." This work was for Pratt and Whitney, manufacturer of military engines. Their objective was to identify reliable multiaxial fatigue models that can used for high cycle fatigue life needs of monolithic engine and airframe materials such as Ti6Al4V. These materials display very little plasticity. Turbine blades are subjected to multiaxial stress in attachment areas. The majority of current multiaxial fatigue work is in low cycle fatigue. Un. of Illinois test data on smooth specimens of solid bars was used for proportional and nonproportional loading. Uniaxial data was from other sources. Torsion tests were run at R=-1, 0.1, and 0.5.with proportional and nonproportional biaxial tests. High torsional mean stress does seem to depress the fatigue life. Triangular path loading shows difference in fatigue life if axial stress is positive or negative. They looked at 22 models for effective stress and critical plane damage parameters. Their best model to fit this data was the Findley model, one of the first to advocate critical plane approach. Conclusions: Critical plane models tend to be more successful than effective stress models at correlating the unaxial and biaxial data. Findley, Fatemi-Socie-Kurath and (?) provided good correlation of the fatigue data. These models all utilize an adjustable parameter (k).

Gavin Horn, Un. of Illinois, reported on "Recent Attempts to Quantify Stress Fields with Thermal Imaging Analysis," with work by Mark Roberts, T. Halverson, and T. Mackin. The thermographic effect was discovered by Lord Kelvin where a change in principal stresses causes a small but detectable change in temperature proportional to the sum of principal stresses. The method is applied to exercise the structure with a small cyclic loading large enough to provide a detectable signal with infra-red technology but with no fatigue damage. Stress Photonics provided instrumentation to detect the stress field. The motivation is to understand the redistribution of stresses in brittle composites. Their method is to apply a ramped load and cycle while observing with TSA until failure occurs. Out of phase imaging shows some damage mechanisms. They are investigating fretting fatigue mechanisms to try and understand contact failures. Another project investigated how laminated polymers used in meat packaging, as landfill liners, and as air bladders behave under cyclic loading. Results indicate cracking can be detected earlier than with the naked eye. Future work is to investigate fatigue mechanisms on air bladders, and locate and quantify damage of composite materials on aging aircraft. One portable application of applied load was to attach a unbalanced fan to the structure of a snowmobile hood. They found high stress areas and additional cracks away from the high stress regions. They are looking at methods combining photoelastic methods to separate principal stresses.

Gregorz Glinka, U. of Waterloo, discussed " Stress Concentrations in Weldments." This work attempts to answer the lingering question of "What stress should be used in weldment analysis? Hot spot stress or structural stress?" When we use finite elements the models don't predict the stress concentration due to the welds geometry. Linear shell elements don't provide proper stress distributions through thickness. An example was a telescoping beam crane. Made from weldments. Used nominal stress at far fields, and structural stress as a linearized local stress, then decomposed into bending and membrane stresses. Knowing the bending and membrane Kt for symmetric joints Fred Lawrence developed a relation to define Kt. Much data is published in the international welding publications. A German author published results based on 1.0mm radius at weld toe. Results did not always agree. Finite element analysis needs a radius at the toe and adjusted mesh density. The beam crane finite element model needed a reinforcement plate at the contact points to prevent passthrough. A structure modeled with shell elements also needs to model the weld geometry. FEA industry should develop a notch element to simulate welds. And output Kt directly. Question: How do we handle variations of weld quality. Answer: Use Monte Carlo technology to arrive at a distribution of Kt's.

Henry Padilla and Thomas Mackin , University of Illinois, discussed " Failure Analysis of a Disc Brake Rotor." Forty seven students got credit in one class for this project. The project started because an F250 truck hauling cattle had a pinging noise coming from the brakes. The project involved microstructure examination of the rotor, a vehicle dynamics calculation, an estimation of the stresses and application of Coffin-Manson equations to predict cycles to failure. Indications of residual stresses were noted from the microstructure examination, which showed flake graphite and slag contamination. The alloy was identified. A calculation assumed an energy distribution of 60% to the front and 40% to the rear brakes. Calculated stopping force was 6412N. Heat calculations in the rotor assumed radial symmetry and neglected hubs and rims. Stresses were estimated using a shrink fit model, and solving for the principal stresses. Analysis predicted approximately 333 cycles to failure. Conclusions: Thermomechanical fatigue drove cracking .Constraints pushed stresses to yield. Predicted life agreed with experience. Key to solving this problem is in removing the constraints.

Fred Lawrence, Un. of Illinois, discussed "The Effect of Cold Laps on the Fatigue Performance of Weldments with Terminations." This project was the work of Steve Dimitrakis. The objective was to determine if the fatigue life of weld terminations could be improved. Weld terminations (Start/Stops) are a common problem at the "bottom of the parrot cage in terms of stress concentrations." An initiation-propagation model is typically used in ground vehicles, civil engineering, and bridge applications. Cracks typically start their growth at weld toes or terminations. Terminations are bad, but ubiquitous. All kinds of welds have terminations. A "stress diffuser" was developed by trial and error with the aid of "ProMechanica," that reduced weld stresses. The diffuser with an undercut of 1 to 2 mm show small improvements, but with undercuts between 0 and 1mm showed large improvements in fatigue life. However, the beneficial effects of the stress diffuser were wiped out if you had cold laps!

Divisional Planning Sessions were held concurrently in two meeting rooms. The future work efforts of these five Divisions will be coordinated by the chairmen and the task group leaders of the respective divisions. Please contact the chairman with any questions or needs. Documentation of future work planned will be included in the full minutes to be distributed before the nest meeting.

Respectfully submittted by: John Hakala - SAE FD&E Vice Chairperson