AC 2007-1201: A SUCCESS STORY: THE SAE BAJA CAR AS A CAPSTONE SENIOR DESIGN PROJECT

Dean Kim, Bradley University

Dean Kim is an Associate Professor of Mechanical Engineering at Bradley University. His teaching and research interests are in measurement and instrumentation, dynamic modeling, feedback control design and implementation, and fluid power systems.

Martin Morris, Bradley University

Martin Morris is a Professor of Mechanical Engineering at Bradley University. His teaching and research interests are in fluid mechanics and thermal sciences.

Richard Deller, Bradley University

Richard Deller is an Associate Professor of Mechanical Engineering at Bradley University. His teaching and research interests are in mechanical design and engines.

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Abstract

The Society of Automotive Engineers (SAE) sponsors regional competitions which are intended to simulate team-based engineering design projects. One such example is the SAE Baja competition (formerly known as the Mini-Baja competition), for which student teams must design and build an off-road that can maneuver robustly through rough terrain. At many universities, the Baja project is organized as a voluntary extra-curricular activity.

This paper describes the success of the Baja team from Bradley University which has worked under the guidelines of a two-semester capstone senior design project course. This eight-member team, consisting entirely of Mechanical Engineering students, can be considered successful based on its work throughout the academic year and based on its performance against 140 teams in the SAE Midwest Baja competition in Elkhorn, WI, in May 2006. This Baja team's success confirms that a design team for a national competition can perform well while operating under the constraints of this course. Also, there are unique benefits for the students and the faculty advisors under this senior design project format. The principles learned by the faculty advisors from this particular project can be used to help future Baja teams or any student project team.

Topics covered in this paper include brief descriptions of the SAE Baja competition and the two-semester capstone senior design sequence, advising guidelines for project teams in general and for the Baja team specifically, and more detailed descriptions of this Baja team's work. Some additional benefits and special experiences enjoyed by this Baja team as a result of their success are discussed.

Introduction

The Society of Automotive Engineers (SAE) sponsors regional competitions that are intended to simulate , team-based engineering design projects. One example is the Aero Design competition, for which student teams design radio-controlled aircraft that must carry cargo. Another example is the SAE Formula competition, for which the student teams design formula-style racing cars. The competition which is the focus of this paper is the SAE Baja competition (formerly known as the Mini-Baja competition), for which student teams must design and build an off-road vehicle that can maneuver robustly through rough terrain. At many universities, the Baja project is organized as a voluntary extra-curricular activity and previous literature has focused on faculty advising such projects under this format.[1] Some of these Baja teams have as many as twenty-five members consisting of students ranging from freshmen to graduate students.

A key component of most engineering curriculums is the capstone senior design project course, for which students must utilize their training and skills to complete the required design tasks. The focus of this paper is the work of the eight-member SAE Baja team which has been performed under the guidelines and constraints of two-semester, capstone senior design course in

the Mechanical Engineering Department at Bradley University. The completed car, shown in Figure 1, has resulted from the team's work in areas such as designing and analyzing the car, performing most of the fabrication, testing under various conditions, and improving the design based on testing results.

This team can be considered successful based on its teamwork during the academic year and on its performance against 140 teams in the SAE Midwest Baja competition in Elkhorn, WI, in May 2006. This team's success is exemplified by its performance in the demanding four-hour Endurance Race, i.e. the team's to drive its car for the entire four hours without any breakdowns. The team's total of 42 completed laps is impressive when compared to the first place team's performance (52 laps) and the inability of 84 teams to complete 30 laps.

This Baja team's success confirms that a design team can perform well in a national competition under the format of this two-semester capstone design course, in contrast to many other universities that organize this project as a voluntary activity. In fact, the authors strongly believe that there are unique benefits of having such a design team work in the guidelines of this two-semester capstone senior design course. First, the course requirements (e.g. progress reports, oral presentations) accurately represent the conditions that engineering students will face in their jobs after graduation. Second, those students who are passionate about this car design project can devote their full energies to it as their senior project, instead of having to split their efforts between a voluntary car project and their required senior design project. Previous literature has been published which describes the design of a Basic Utility Vehicle under a two-semester senior design sequence for a much smaller national competition (i.e. consisting of thirteen teams). [2]

The remainder of the paper is organized as follows. The SAE Baja competition is discussed briefly. The two-semester senior design capstone course Mechanical Engineering Department at Bradley University is described. General guidelines for successful advisement of any senior design project are discussed. Specific guidelines for successful advisement of the Baja team are provided, including important tasks and milestones. Finally, some of the unique benefits and special experiences possible for a successful Baja team are discussed, such as the opportunity to perform extensive tests at the facility of a nearby engineering corporation.

SAE Baja Design Competition

SAE Baja (formerly known as SAE Mini-Baja) annually holds three regional competitions, each of which typically spans three to four days. Each team must design and build an off-road vehicle that can maneuver robustly through rough terrain, within limits established by the rules. All vehicles are powered by identical ten-horsepower engines donated by a prominent engine manufacturer. The use of the same engine by all teams is intended to create a more challenging design test. Still, the intention is that each team's overall design will be significantly different from the previous year's design.

Each team receives a score out of a maximum possible point total of 1000, which is based on a combination of static events and dynamic events. The static events score is based on the team's cost report and design report which must be submitted to SAE prior to the competition. The dynamic events score is based on the team's performance at the competition in the following:

Acceleration, Maneuverability, Mud Bog, Chain Pull, and Endurance Race. The Endurance Race score, with a maximum possible score of 400, represents the bulk of the team's dynamic events performance. The Endurance Race score is based on the number of laps that the team's car can complete on the demanding 1.4 mile course within four hours. The Endurance course is intended to expose any design flaw in each team's vehicle. Therefore, the ability to complete laps continuously for the entire four hours is considered an outstanding achievement for any Baja team. Endurance courses for this competition typically consist of segments with names such as "Sand Trap," "Rock Field," and "Log Field."

At many universities, the Baja project is organized as a voluntary extra-curricular activity. This paper chronicles the success of an eight-member Baja team which worked under the guidelines of a two-semester capstone senior design course in the authors' is described in the next section.

Two-Semester Senior Design Course Sequence

The senior capstone design project course Mechanical Engineering Department at Bradley University spans two sequential semesters, specifically the Fall and Spring semesters of the academic year. A single professor, serves as the course coordinator of this senior project sequence. The course coordinator assigns each senior student to a project team. One factor thatinfluences these assignments is each student's indicated areas of interest solicited during mandatory organizational meeting held during the previous Spring semester. Certainly, projects such as the Baja car have the best chance for success when the involved students are passionate about the subject. Before their senior year, students are given the opportunity to demonstrate their passion for the Baja project by helping and learning from earlier Baja teams.

Each project has an official sponsor (i.e. "client") and the typical project team consists of three or four undergraduate students and at least one faculty advisor. Previousresults from these senior projects have been presented in technical publications at past engineering conferences[3-4] While most of these senior projects have industrial clients, the client for this Baja car project is Bradley University, which is represented by the Mechanical Engineering Department. The Baja car project consists of two four-person teams that must work together under the constraints of time and budget. One team focuses on the Frame and Suspension, and the other team focuses on the Engine and Drivetrain. Each four-person team has an official Team Captain and one of these Team Captains is chosen to be the overall Project Leader. This total team size of eight members seems to be ideal for successful design of the Baja car while requiring significant contribution of effort from each team member. In contrast, previous literature that describes the efforts of a 35-team Baja team under a Senior Design Project sequence has indicated the difficulty of monitoring the activities and contributions of each team member.[5]

Each team is expected to schedule at least one meeting each week among themselves, in addition to a weekly meeting with its faculty advisors. The faculty advisorsfor this Baja project have learned that the most effective policy is to conduct a single weekly meeting with all eight students, instead of meeting with each four-person team separately. Each team is expected to develop a weekly task sheet which specifies the duties each member will perform for the project.

These weekly task sheets are archived to assess the contribution of each team member for the project duration.

This design project course requires that each student team provide an initial proposal, regular progress reports, three oral presentations to classmates and faculty, and at least one presentation to the client. Each team's initial proposal, which is due by mid-October, includes a schedule with milestones, a budget, and a list of deliverables. This list of deliverables represents the items that each design team must provide to the client by the end of Spring semester in order to complete the project and graduate. The two four-person teams for the Baja car must provide separate proposals even as they work to complete the single car. The expected deliverables for this Baja project include the completed car and CD's which contain the engineering design work and all related documentation.

Guidelines for Advising Successful Student Project Teams

In this section, guidelines are discussed which can help professors successfully advise student project teams, with specific examples being given for this Baja car project.

First, the faculty advisors must help all team members become actively involved immediately and for the project duration. Especially at the start of the project in August, the team members can be expected to be very enthusiastic, but they may not know how best to utilize that enthusiasm and energy to complete the project by the following May.

Specific steps for utilizing the team's enthusiasm at the start of the project include:

1) Each team member must honestly assess his/her abilities and experiences with regard to the project. For example, that person may have more experience than other team members in areas such as machining and usage of computer-aided design software.

2) Each team member should become familiar with the background associated with the assigned project, such as understanding the uses and capabilities of the particular technology. For projects such as the Baja car, each team member should drive the previous year's vehicle and then document observations and ideas for modifications and improvements.

3) For projects such as the Baja car, each team member should become completely familiar with the competition rules, including the design constraints.[1] The Baja rules document consists of 75-80 pages.

4) The faculty advisors can emphasize to team members that their hard work and initial successes can provide additional benefits and special experiences which will further enhance their project experience. Specific examples for the 2005-2006 Baja team are discussed in a later section.

5) Finally, the faculty advisors can encourage the team members further by displaying their own genuine enthusiasm for the project.

Second, while the faculty advisors must insist that the team work and act professionally, the faculty advisors also must be patient as the students are still learning the entire "engineering/team" process. Examples include:

1) Because the students may not have much experience with meetings, the faculty advisors need to guide them in developing critical skills such as setting agendas, conducting effective and time-efficient meetings, and writing minutes of meetings.

2) Students must be able to work with their teammates, which includes handling differences of opinion in a respectful, professional manner. Each team member should feel free to provide ideas and ask questions through discussions with teammates and with faculty advisors. The advisors need to encourage this type of atmosphere and demonstrate this type of professional behavior themselves.

3) Students need to learn how to interact effectively and respectfully with people within the university (e.g. faculty advisors, secretaries, administrative personnel) and outside the university (e.g. vendors, service-providers, SAE representatives).

4) Students need to learn the importance of meeting deadlines, in particular for a time-constrained project such as the Baja car. The faculty advisors need to monitor each team's progress.

5) Students need to learn the importance of performing project work under budget constraints. For each academic year, the Baja team's total budget is fixed at $ 2,500. Funds are solicited from external donors by the faculty advisors. One initial task for each Baja team is to determine which parts (if any) from the previous year's car can be re-used.

6) The faculty advisors need to mentor each Team Captain and overall Project Leader to help ensure that these individuals are helping the design teams to perform well and make good progress.

Specific Guidelines for Advising the Successful Baja Project Team

The success of the 2005-2006 Baja team can be attributed to use of the general principles described in the previous section, and to the Baja experience gained by three of its team members as juniors during the 2004-2005 academic year, during which there was no Baja senior project team. Instead, these three students had worked on improving a previous Baja car as an independent study project, and then had participated in the SAE Mini-Baja 100 competition in Tucson, AZ, in June 2005.

Next, specific details are discussed regarding the work of this Baja team to design, build, test, and refine the Baja car during the August 2005 to May 2006 time period. The date for each primary milestone is provided. Under each milestone, the necessary steps leading up to achieving that milestone are listed.

1) Perform the initial steps as described in previous section (August)

2) Finalize frame design (by December 5th) – May need several iterations of these steps

   a) Obtain steel (hopefully, it will be donated)
   b) Draw new frame on paper
   c) Represent frame in drafting software
   d) Construct PVC tube model
   e) Perform necessary stress analysis using software

      - Figure 2 shows the model of the entire Baja car as drawn in the design software.

   f) Be clear how all other components (e.g. engine, drivetrain, steering, brakes) will fit on this new frame

3) Finish primary frame construction (by January 15th)

   a) Cut/bend/cope the steel pieces
   b) Use tack welds (i.e. temporary welds) to indicate clearly to the expert welder how the finished frame should look
   c) Again, make sure how all other components (e.g. engine, drivetrain, steering, brakes) will fit on this new frame

      - Of particular importance is determining where all tabs should be placed

4) Finish rolling chassis (by February 15th)

5) Finish running car (by April 10th)

6) Finish testing and modifications to car (by May 10th)

Major lessons have been learned from this Baja team's ability to reach each milestone on schedule. First, even though each Baja team is predominantly a senior activity, the faculty advisors and the Baja team members must actively mentor the interested younger engineering students in the project for the sake of future Baja design efforts. The knowledge and experience which they obtain before their senior year is invaluable. Previous literature has made similar recommendations regarding the design of a Human Power Vehicle under a two-semester Senior Design sequence.[6] Second, the team should perform as much of its own machining as possible, especially for the frame. In fact, the only machining performed by an expert welder from outside the university is the final welding after the team has applied the tack welds. Third, throughout the timeline of the project, the necessary parts and materials must be ordered well in advance. This is to prevent time from being wasted while waiting for delivery of such items.

Additional Benefits and Special Experiences for this Successful Baja Team

This section describes some of the additional benefits and special experiences made available

to this Baja team due to its hard work and excellent progress. Certainly, teams for other types of design projects can have similar experiences as a result of their excellent achievement.

First, a successful Baja team can make final design improvements in the April-May period after its initial testing. Examples for this team include learning of the need for a stronger steel sprocket on the rear axle, and realizing the benefits of adding a driver-activated shifting mechanism (i.e. for HIGH-LOW gear settings) in the cockpit. For any Baja team, such design improvements cannot be made if the team has to work feverishly simply to get the car built in time for the May competition.

Second, a successful Baja team can obtain funds for design improvements from unexpected sources. Fortunately, the Dean of the Bradley University College of Engineering and Technology is keenly interested in this Baja team's work, due to this person's experience as a Baja faculty advisor at a previous university. Because of its progress, this team benefit from College funds to improve the car's performance, specifically from the purchase of new rear springs for a smoother ride.

Third, a successful Baja team can enjoy experiences from providers outside the university environment. This was demonstrated by the opportunity for this particular Baja team to perform extensive tests at the facility of a nearby major corporation, in order to prepare for the competition and to acquire data (e.g. strain measurements) for validating computational models and design improvements. As an example, Figure 3 shows the location of three strain rosettes (R1, R2, R3), each of which measures strain in three directions (i.e. T, F, and L) as indicated in Figure 4 The strain data shown in Figure 4 demonstrates that gauge "R3" is experiencing the most strain. Certainly, the team's experience of testing and driving on a demanding custom-made Endurance Course ranks as one of the highlights of each member's entire undergraduate experience.

Conclusion

This paper has described the success of the Baja team of Bradley University under the format of the two-semester capstone senior design course of the Mechanical Engineering Department. This eight-member team's success confirms that such a design team can perform well under such a format throughout the academic year and at the national competition. General guidelines for successful advisement of any student design project, and specific guidelines for successful advisement of the Baja team have been provided. The benefits and potential special experiences that are possible for a successful team have been described. As a final note, the authors can verify that their experiences as faculty advisors for this Baja design project are much more enjoyable and rewarding when the team performs well throughout the project and at the national competition. It is the authors' hope that other fellow professors can experience the same satisfaction in advising and mentoring similarly successful teams.

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Figure 1 Completed Baja Car for 2005-2006 Bradley University Team

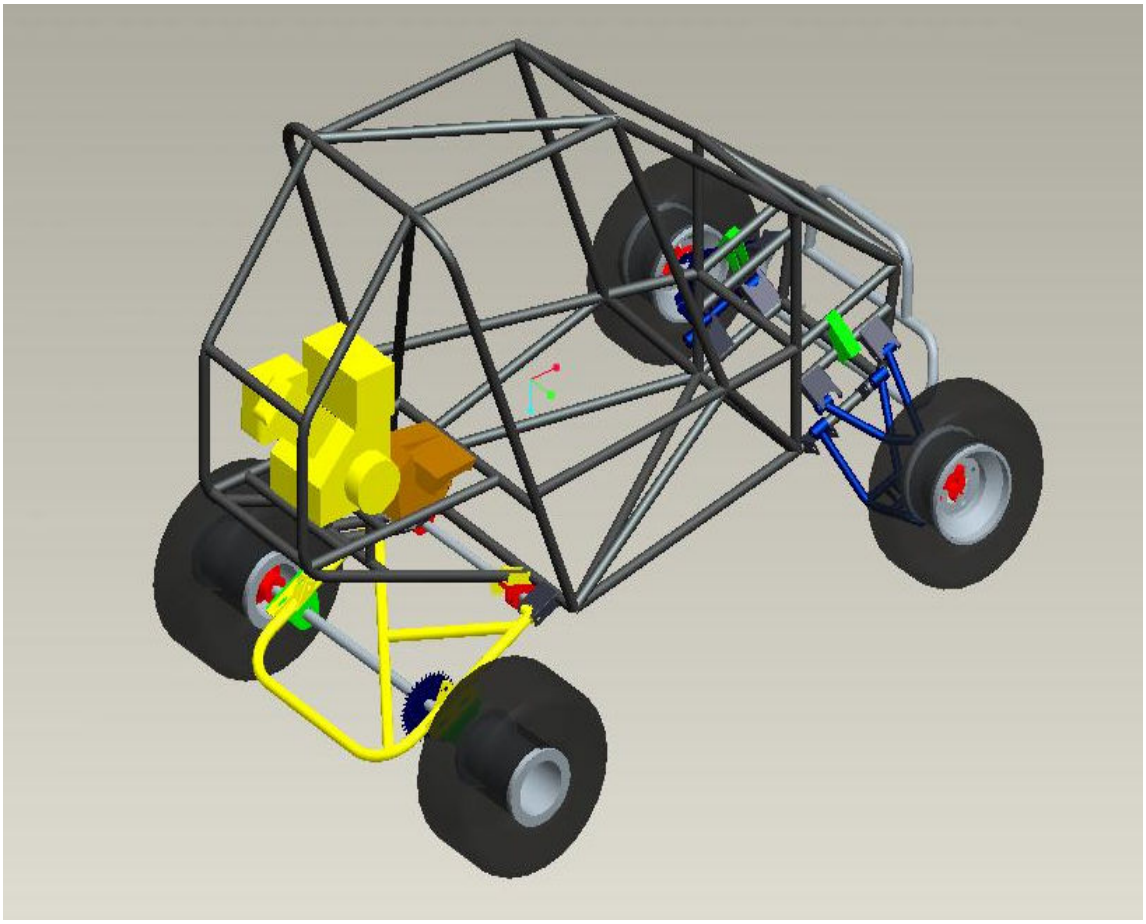
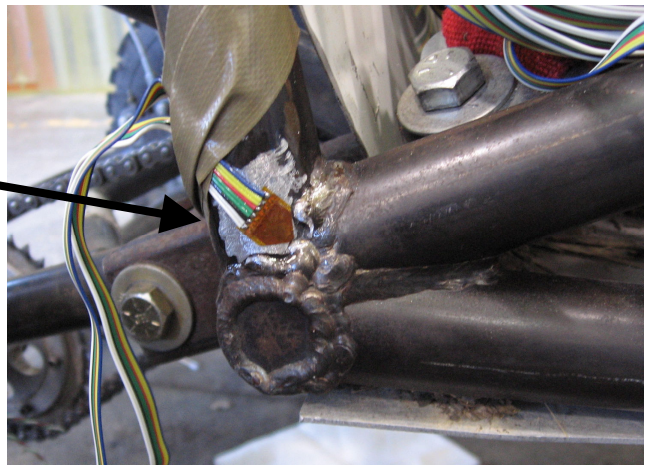
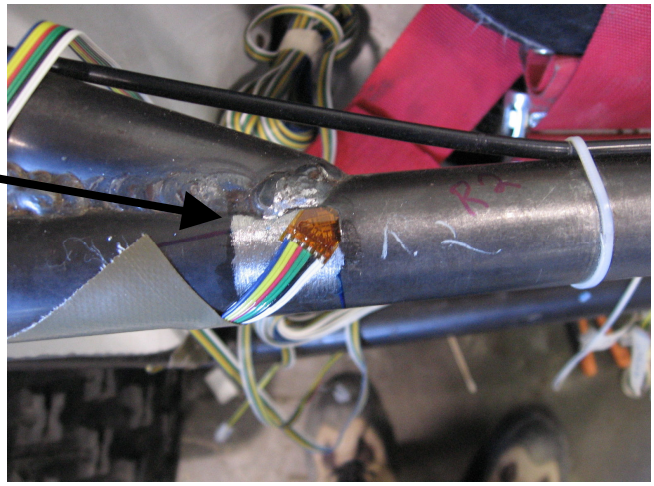


Figure 2 Model of Baja Car in Design Software

Strain Rosette “R1”



Strain Rosette “R2”



Strain Rosette “R3”

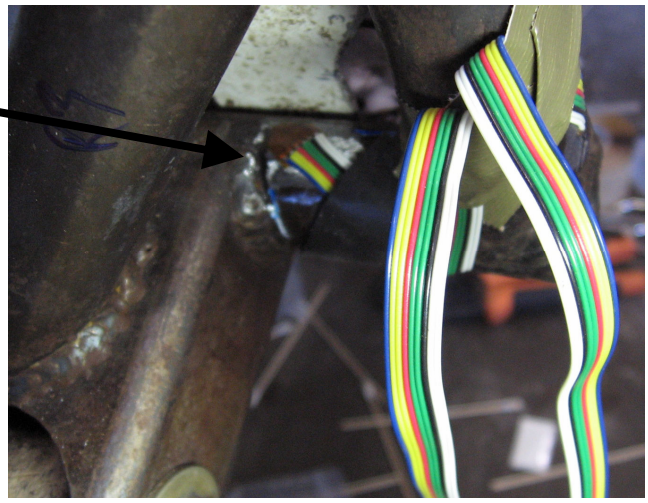


Figure 3 Representative Strain Rosette Locations

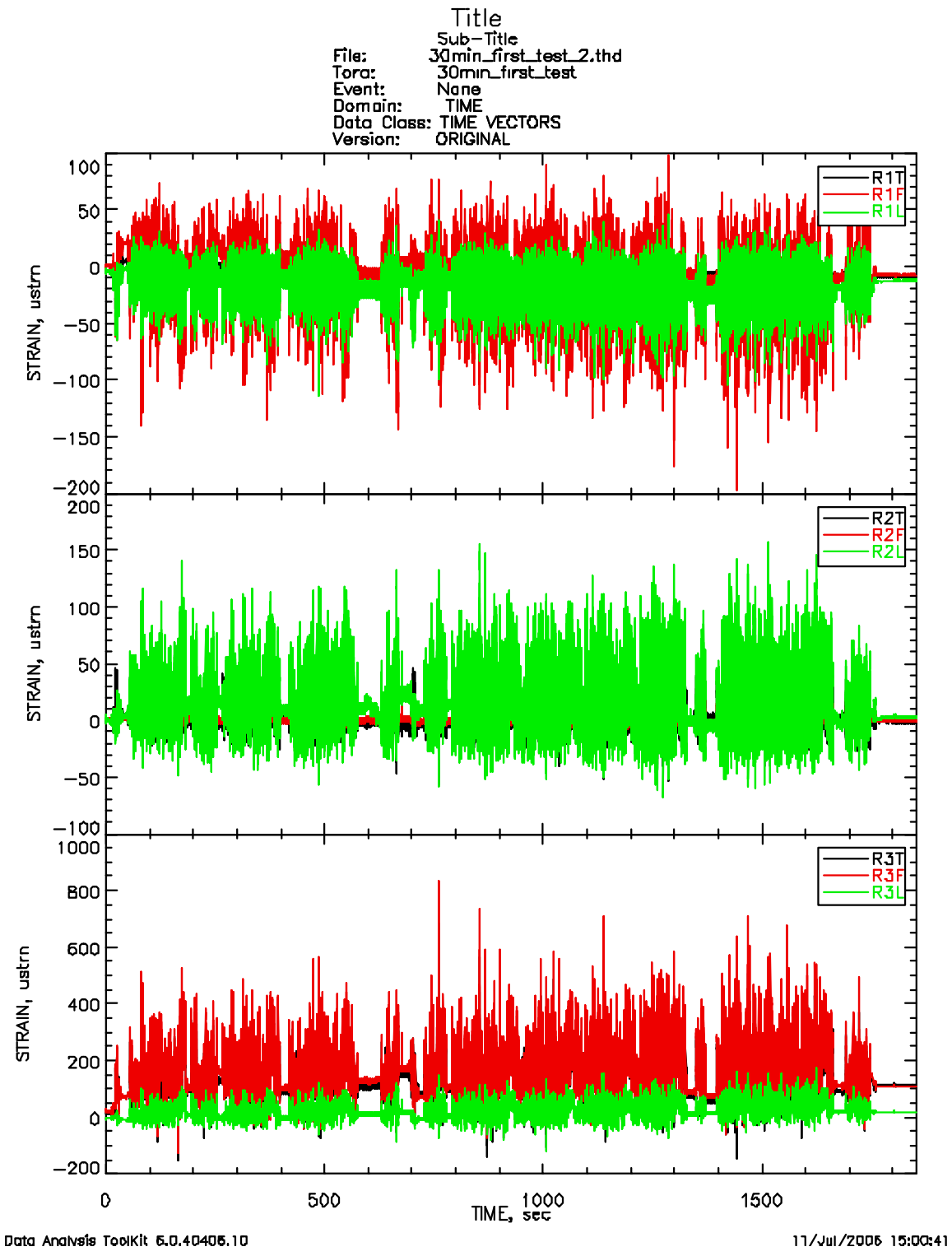


Figure 4 Data from Strain Rosettes (R1, R2, R3)