2006-837: A SENIOR DESIGN PROJECT TEAM OF ENGINEERING AND ENGINEERING TECHNOLOGY STUDENTS

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A Senior Design Project Team of Engineering and Engineering Technology Students

Abstract

During the senior year, both mechanical engineering (ME) and mechanical engineering technology (MET) students take a two-course sequence in senior design. Each version of the course includes a design project and acts as a capstone course for the respective program. These design courses and the respective student projects have traditionally been completely independent, even though university resources, such as machine shops and laboratory space, are shared between the programs.

During the past academic year, a project team made up of both ME and MET students embarked on a joint senior project to enter the Human Powered Vehicle (HPV) Challenge, an annual competition sponsored by the American Society of Mechanical Engineers (ASME). Held each spring, the HPV Challenge is a competition in which teams of students design and build a vehicle powered solely by human power. Vehicle classes include single rider, multi-person, and practical, each with their own design goals and constraints. The competition includes design, sprint, endurance, and utility events.

The pairing of students from differing academic and experience backgrounds on a design project of this scope proved most interesting, with some expected and also some unexpected results. The varied preparation of the group members offered great potential to form an outstanding design team, and they were largely successful in achieving their goals. This unique project also prepared the students for real world experiences, where diverse groups often work together towards a common goal.

Introduction

Mechanical engineering (ME) and mechanical engineering technology (MET) students both take two senior design courses in their respective programs during their senior year that act as a capstone course. The capstone course exposes the students to open-ended problems and also provides a framework for their evaluation.[1] Incorporating joint projects between the programs could better utilize university resources, such as machine shops and laboratory space.

A project team comprised of both ME and MET students at The University of North Carolina at Charlotte (UNCC) embarked on a joint senior project to enter the Human Powered Vehicle (HPV) Challenge, an annual competition sponsored by the American Society of Mechanical Engineers (ASME). The HPV Challenge is a competition in which teams of students design and build a vehicle powered solely by human power (i.e. no energy storage or input devices are allowed, such as a flywheel or battery). A team can pursue vehicle classes of single rider, multi-person, and practical, each with their own design goals and constraints. The competition includes design, sprint, endurance, and utility events.

Grouping of ME and MET students on a design project of this scope, where a vehicle is designed and built from scratch in a period of about eight months, produced some expected and also some unexpected results. Each group of students came to the project from different backgrounds. The MET students had transferred to the university after two years in a community college setting, while the ME students had taken the traditional route from high school to university. The MET students had more varied life experiences, such as military service and industrial experience, while the ME students had primarily studied full time since high school. And of course, there were the differences in the two curricula, where the MET students had followed a more hands-on program of study, while the ME coursework was more theoretical in emphasis, focusing in mathematical modeling and analysis.

Bringing these two diverse groups of students together on a single project had many potential advantages. The MET students would be expected to offer superior hands on skills, e.g. machining, welding, etc., while the ME students should bring superior skills in analysis, such as the ability to perform finite element analysis (FEA), computational fluid dynamics (CFD), mathematical modeling, and other advanced design functions. The MET students would gain a deeper understanding of the theoretical modeling of design problems. Similarly, the ME students would gain a more in-depth understanding of the physical relationships governing the theoretical models, and would experience the hands-on application of their principles. Through the combined effort, the ME and MET students would both gain a clearer understanding and appreciation for the job functions of engineers and engineering technologists, including where they overlap and where they differ.[2] As a final benefit, the project should help prepare the students for real world experiences, where diverse groups often work together towards a common goal.[3]

Concept & Planning

The first step in developing an entry for the HPV Challenge is deciding on the major parameters of the vehicle, such as number of riders, wheel layout, drive system, fairing placement, etc. Differences between the two student groups first became apparent in this stage of the project. The ME students primarily focused on theoretical models, where the MET students' focused on practical, hands-on experience models.

Many of the ME students' conceptualizations were basically impractical designs that would be infeasible or impossible to build. One example was a drive concept consisting of a shaft drive with pedals attached directly to the drive wheel via a solid shaft, so as to eliminate the need for a chain. The purported advantage was the possibility of a linear pedal motion, rather than a traditional circular motion. Unfortunately, design issues, such as weight, shaft strength to prevent buckling, and overall practicality, where not considered in the proposal.

If the ME students had performed adequate research of the ideas they proposed, they would have recognized that the designs were not practical proposals. Many of the "new" designs proposed by the ME students had already been analyzed, tested, and proven (or disproven) as valid or effective bicycle designs. Many of the designs dated from the turn of the 20th century, when bicycling was a prominent mode of transportation. In effect, the ME students wanted to focus on reinventing the wheel when, based on this project's design goals, the focus needed to be on improving the wheel. The background of the MET students provided them with the knowledge of what worked and what did not work, or at least knowledge of what designs were used and had been proven effective by the bicycle industry.

Within the competition rules[4], ASME leaves the HPV design open to creative concepts, encouraging innovative and/or alternative designs. However, many of the past student designs closely resemble what the bicycle industry calls a recumbent bicycle, as shown in Figure 1.

Figure 1 – Commercial Recumbent Bicycle[5]

In commercial recumbent bicycles, two main types exist; one category made for speed and the other made for comfort. Speed bikes, which can obtain speeds in excess of 80 miles per hour, are fully faired, to reduce wind resistance, and are generally not comfortable for the rider, as evidenced in Figure 2. Comfort recumbents, as the name suggests, are designed for rider comfort over long rides, in the range of 40 miles or more. After much discussion over supplies, costs, and project goals, the UNCC team decided to focus their design on rider comfort.

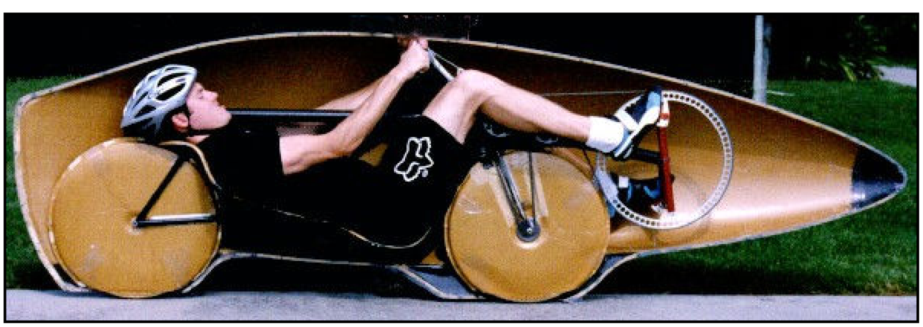

Figure 2 – Cut-Away View of a Speed Bike[6]

Detailed Design

An empirical approach, proposed by the MET students, was used to determine the optimum comfort position for the rider. Pictures were taken of the rider(s) in what they considered a comfortable position. Then, from the position, scaled reference points were established and used to determine vehicle geometry as shown in Figure 3.

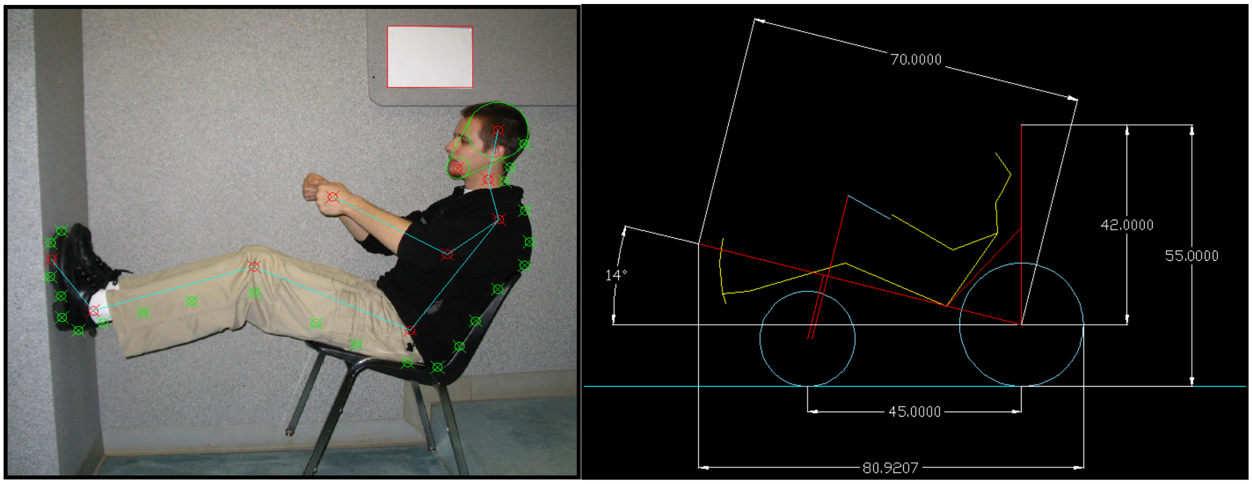

Figure 3 – Reference Points for Rider Position and Corresponding Vehicle Geometry

An ME theoretical approach[7] was used to determine the optimum location of the rider to the vehicle. Counterintuitive to the adage that a lower center of gravity is more stable than a higher center of gravity, a higher center of gravity was chosen. Reasoning is similar to why it is easier to balance a rod, with a mass on one end of the rod, on your hand, where the mass is on the end away from your hand, rather than at the end resting on your hand; see Figure 4.

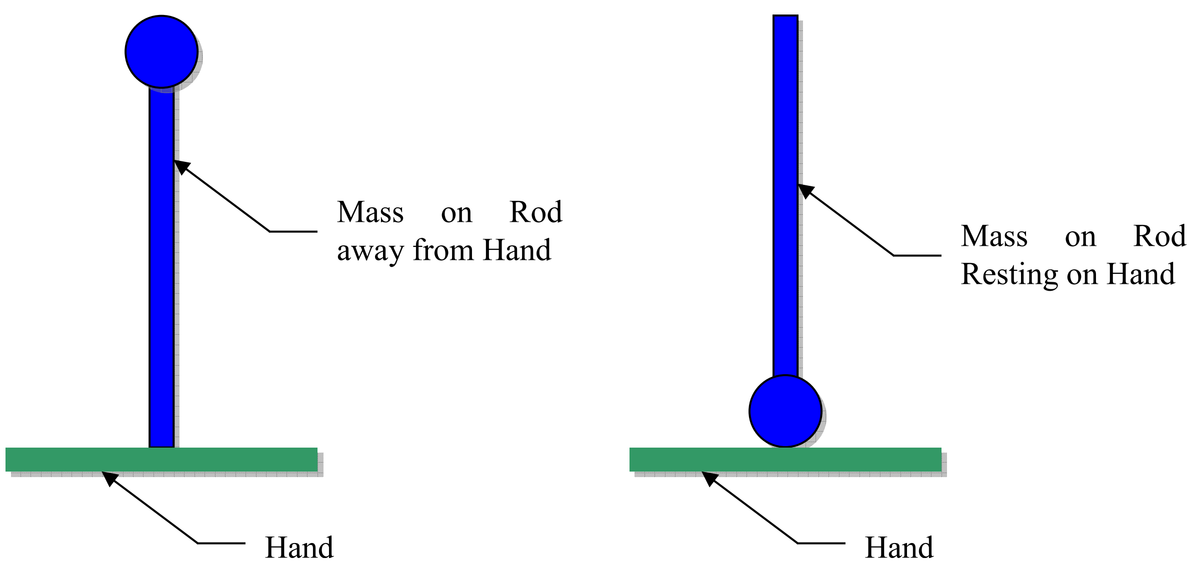

Figure 4 – Balancing a Mass on a Rod

With the detailed design now well underway, the decision was made to divide remaining responsibilities among the team members. The MET students would continue with the design of the vehicle, while the ME students would pursue detailed design of the fairing.

It was here that another difference between the students became apparent, with the ME students failing to completely think through the practicality of a design. For example, a fairing made from Ceconite[8], a strong and light weight material used to cover airplane wings, was proposed. While the material choice was innovative and showed potential as an alternative to fiberglass, its support structure was not originally considered in the design. Since Ceconite does not maintain rigidity on its own, an underlying support structure is required. Once the support structure was considered, its weight alone was estimated at about 60 pounds, obviously removing any weight advantage over fiberglass. In addition, no feasible means of attaching the support structure to the rest of the vehicle was considered. This continued the trend of the ME students proposing ideas that were creative and "outside the box", but lacking adequate research and analysis to show them as superior to current methods or designs.

Engineering Analysis

Both groups of students utilized solid modeling for design and analysis purposes; see Figure 5. The ME students performed an FEA of the frame design, producing stress and deflection plots, which were used to optimize tube wall thicknesses and diameters; see Figure 6. With some faculty assistance, the MET students were able to perform a simple FEA of the seat bracket design, which was used to optimize the design based on the stress and deflection produced from a static load as shown in Figure 7. This experience reinforced to the MET students the usefulness of design analysis tools, such as FEA or CFD, and the difficulty of modeling with FEA or CFD on some designs. The MET curriculum does not cover the theory behind an FEA or CFD software package where the theory is covered in the ME curriculum. An understanding of FEA theory is essential in both deciding how to properly model a problem and in interpreting the result.

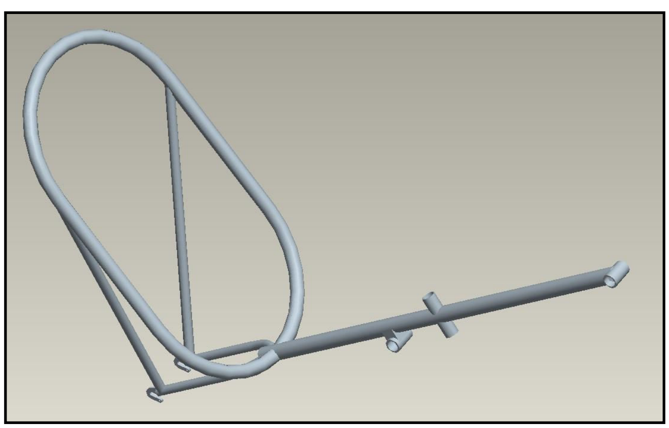

Figure 5 – Solid Model of Frame

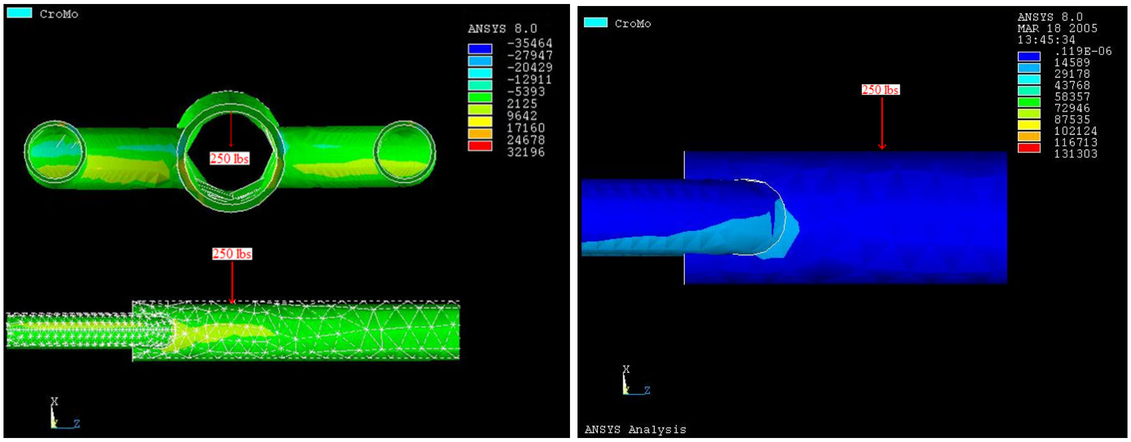

Figure 6 – Finite Element Analysis of Frame

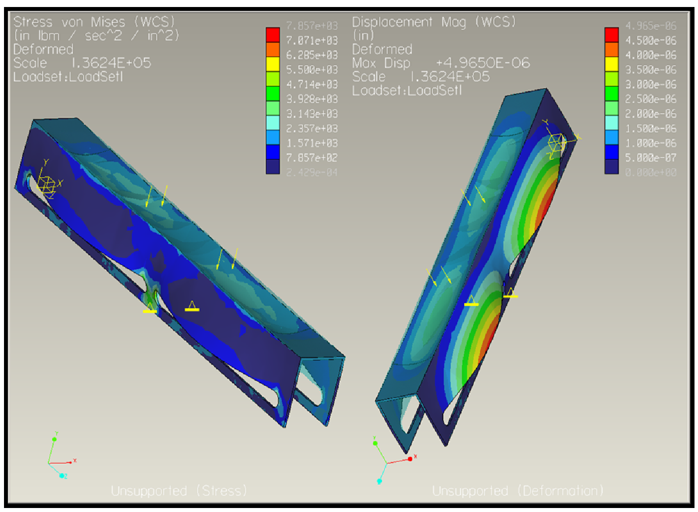

Figure 7 – Finite Element Analysis of Seat Bracket

Engineering Drawings

As stated earlier, both groups of students were able to generate solid models as part of the design process. When it came time to generate a set of engineering drawings, such as the assembly drawing shown in Figure 8, the ME students failed to produce them. A complete set of engineering drawings is a required element of the design report. It quickly became clear that the ME students simply did not have an understanding of what was required, that a set of engineering drawings need to be fully dimensioned, including the bill of materials, specification of processes (e.g. heat treatment), etc. The ME students were also unfamiliar with assigning critical dimensions with the design and function of the part in mind. They also did not seem to consider issues of fabrication and assembly. Again, this was a case where the ME students had relevant theoretical concepts, but had little practical experience or knowledge to aid in completion of the design.

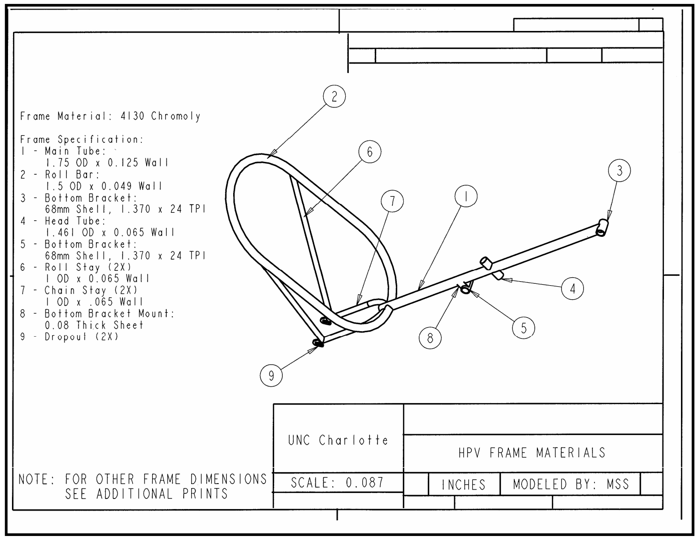

Figure 8 – HPV Frame Assembly and Bill of Materials

Getting it Built

As expected, the construction phase is where the differing backgrounds of the two student groups became most apparent. The ME students were unfamiliar with basic shop machinery and processes and failed to request assistance or guidance before starting an unfamiliar task. The following events occurred during fabrication of the vehicle:

- Two of the three ME students on the project failed their initial shop safety tests. One of the students received permission to retake it and passed; the other elected not to retake the test and stated that he did not belong in a shop.

- One of the ME students responsible for making a wooden stand to support the HPV attempted to cut a 2 x 4 wooden board with a sheetrock saw. When this did not work, the ME student sought assistance in cutting it with a band saw, which worked much better.

- One of the ME students who had no previous welding experience expressed an interest in learning how to TIG weld so he could help with fabricating the frame. The student quickly realized the substantial amount of time and effort required to become a proficient welder, and quickly lost interest, stating that he had no idea that it required so much skill.

- An ME student took on the task of machining a part on the mill. Rather than rough cut the basic shape with a vertical or horizontal saw prior to milling, the student milled the entire part from a stock piece of material. This took much longer than was necessary, and in the process, completely dulled an end mill.

In the end, the MET students did the majority of the shop work, involving the ME students as much as their skills permitted (e.g. painting the frame and building a wooden stand for the HPV). This experience provided the ME students with an appreciation for what occurs in the shop and why certain design concepts would not work from a practical standpoint. Below are a few photos of the fabrication process, which include fixture fabrication/welding, Magnaflux® testing of welds for cracks, part-fit assembly, and the finished product:




The Competition

There were many challenges faced in turning a design concept into a completed vehicle. It is not uncommon for teams to fail to complete a project in advance of the competition. UNCC's combined team of ME and MET students was successful in overcoming the obstacles faced in concept, design, analysis, fabrication, and testing of the vehicle. UNCC's team finished 9th place overall out of a field of 20 competitors in the single-rider category of the ASME sponsored 2005 East Coast HPV competition, which was held in Tuscaloosa, Alabama and hosted by The University of Alabama, Tuscaloosa.

Successes & Failures

Overall the project was a success. The team was successful in designing and building an HPV and participating in the ASME competition. The team did not win any trophies at the competition; however, much of the performance competition has to do with the physical condition of the riders and not the quality of the design or fabrication workmanship of the HPV. Some of the teams that won top positions in the performance portions experienced mechanical failures during the competition. The UNCC entry experienced no such failures.

Both groups of students gained experience working on a project team comprised of people with diverse backgrounds and skill sets. All students learned that a project team does not always function as expected, with one team member's strengths overlapping another's weaknesses, resulting in a unified group with optimized strength. Surprisingly, more often than not, significant gaps existed between the strengths and weaknesses of individual members. Learning how to compensate as a group was an essential lesson learned, and was critical to the ultimate success of the project.

Even though the ME students did little of the shop related work, they did gain some understanding of why physical manufacturing constraints can and often do govern product design. Examples included the difficulty of welding very thin materials, welding steel to aluminum, placement of components, maintaining design tolerance with available tooling, fabrication time required to complete a job, and machining of thin materials with conventional machining methods.

The fairing design, for which the ME students had primary responsibility, was a failure. The design was never fully developed, was constantly changing, and had notable flaws, such as excess weight, in spite of proposed innovations such as the use of Ceconite. In the second semester of the project, the fairing design continued to lag and no real analysis work had been done. Although CFD software was available for analysis, none was completed. As the competition neared, it became apparent that backup plans had to be made, as the competition rules require all vehicles be equipped with a fairing that covers at a minimum 1/3 of the vehicle's frontal area. A pre-fabricated, commercially available fairing was purchased and attached to the front of the vehicle, as can be seen in Figure 9.

Figure 9 – UNC Charlotte Team Members and Vehicle at Design Presentation

The failure of one part of the team did not bring down the whole team, but it did weaken it. Had the fairing design been a success, the team most likely would have scored higher in both the design competition and the performance portions of the event.

Conclusion

A senior design project team of engineering and engineering technology students designed and built a human powered vehicle for entry into ASME's Human Powered Vehicle Challenge. The students came to the project team with varied backgrounds that were consistent with preparation in mechanical engineering and mechanical engineering technology. The combined team had many potential advantages, including the MET student's hands-on skills and the ME student's skills in analysis, using tools such as FEA and CFD, and a deeper understanding of how to theoretically model a problem.

There were expected results, such as the MET student's knowledge of machining, welding, and other physical processes, and the ME student's ability to perform an FEA plot of stress and deflection for making design decisions, such as tube wall thickness. Also, as expected, each group of students gained an appreciation and some understanding of the other's strengths, weaknesses, and their respective skill sets. The MET students gained an appreciation for the usefulness of design analysis tools, such as FEA and CFD, and the difficulty of accurately modeling a design for FEA and/or CFD analysis. The ME students gained an understanding of how physical manufacturing constraints govern product design, learned about basic manufacturing processes, and also learned the content and importance of detailed engineering drawings.

There were also some unexpected results. For one, the MET students possessed more theoretical knowledge than was anticipated. From a basic understanding of solid modeling and strength of materials, the MET students were able to perform some basic FEA of stress and deflection and make design decisions based on the results. Another unexpected result was the ME students' failure to conceptualize a realizable design, that is, something that could be built and meet design qualifications. Their unfamiliarity with basic machine tools, processes, and engineering drawings was also somewhat of a surprise. The ME students on average did not perform as well in their senior design class as the MET students did in theirs. Overall, the ME department was displeased with the performance of their students on this project. It is a reasonable expectation that this particular group of students is not representative of the majority of students in the ME program.

The project showed that a project team comprised of ME students, with proficient theoretical design and analysis skills, and MET students, with hands-on practical knowledge of design and shop work, has high potential for success. Overlapping knowledge between the two groups will exist, and can be beneficial to both groups and to the project as a whole. One cannot expect a student group such as this to work together seamlessly and fluently for the entire project, just as one cannot realistically have that expectation for any group of students, regardless of their background. With experience comes education, and all members of this team will take with them many lessons learned during the course of the project.

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