2006-2546: ENGINEERING EDUCATION THROUGH REVERSE ENGINEERING

Pedro Orta, ITESM Monterrey

Ricardo Ramirez Medoza, Institute Tecnologico De Monterrey

Hugo Elizalde, Monterrey Tech

David Guerra, Monterrey Tech

USE OF REVERSE ENGINEERING AS A TEACHING TOOLS IN MECHANICAL ENGINEERING EDUCATION

ABSTRACT:

Our University has been working in a new teaching-learning model for several years.. .. The fundamentals of the Engineering Education are the active learning technique and Reverse Engineering based on the assembly and construction of an experimental aircraft RV-10. Reverse Engineering (RE) teaching technique is an invaluable teaching tool used by the Mechanical Engineering Faculty to learn from the original structure and design, which is equivalent to going backwards through the development of the product. The main issues handled by the RE teaching technique reviewed here are: knowledge generated by the practical assembly of an experimental airplane; generation of reliable, complete and fully detailed models describing the airplane behaviour as well as its parts and subsystems; development of specifications for techniques, methods and procedures for manufacturing aircraft components

KEYWORDS: ***Reverse Engineering, Active Learning, Mechanical Engineering Education***

1. INTRODUCTION.

As part of its 2015's mission aiming at developing values, attitudes and abilities in its students, the ITESM[1] has carried out a complete re-design of its educational system, dramatically challenging the traditional environment based on giving lectures.

In this new model, the main role of the learning process is assumed by the student rather than the teacher. Collaborative learning is combined with individual work, so that the exploration of the student complements, but does not replaces, lectures. In addition, established teaching techniques -whose efficiency has been already demonstrated- are applied and incorporated into the didactic processes. On the other hand, the underlying educational model makes extensive use of information technology that offers, enriches and enhances the learning process. In short, the student occupies a main role, revolving around his/her self-learning, and following fundamental principles such as *constructivism and experimentation* [1, 2].

The active-learning (AL) technique is specifically emphasized in this model [2], following these basic principles:

- Students must discover new phenomena and concepts by themselves, and they must be able to relate these concepts with previous knowledge.
- Motivation is the key driving force.
- Team work is strongly promoted.
- More established techniques such as Problem Based Learning (PBL) and Project Oriented Learning (POL) are incorporated into this model [3, 4]. The learning process is inductive instead of deductive, so the students can develop skills and abilities that demand an active participation. Creativity and innovation are formally promoted by different activities.

[1] "Instituto Tecnológico y de Estudios Superiores de Monterrey".

In this paper, the authors aim at investigating the applicability of Reverse Engineering (RE) as a novel teaching tool via the assembly, experimental testing, control and instrumentation of an RV-10 aircraft, within the context of computational modeling of solids, analytical and numerical modeling of the dynamics involved, and virtual modeling of real environments. This will result in field data used for a complete re-design, as well as for developing techniques, methods and procedures.

The RV-10 experimental Aircraft is a four seat and with a single-phase engine. The project has been funded by ITESM-Campus Monterrey and *ICKTAR Engineering Services Company*, with the main purpose of generating knowledge and Engineering techniques for the design, manufacture, analysis and control of aircrafts

The *ICKTAR Engineering Services Company* is giving guidence in the airplane assembly and is providing the RV-10 airplane and also are acting as a project leader. On the other hand, the ITESM will supply facilities to manufacture and assembly the airplane and all the necessary equipment (electronic, electric, computer, aeronautics analysis and modeling software). The underlying academic project will be carried out using an appropriate Reverse Engineering Learning Technique.

This educational project is used as a framework for re-designing the learning environment for under- and graduate engineering careers offered at the ITESM, such as Mechanical Engineering, Mechatronics Engineering and Electrical and Electronic Engineering. The framework fits within a current major trend in engineering education, seeking to develop specific skills for newly graduates entering the job market. Thanks to this new educative system, students will be immersed into a fertile environment for innovation, therefore having an edge when seeking their first job.

The paper is organized as follows: Section 2 presents up-to-date information concerning aerospace industry in Mexico. Section 3 reviews RE (Reverse Engineering) as a learning technique. Section 4 details the on-going project. Section 5 exposes good and bad lessons learned from project developments in the last year, and finally Section 6 summarizes the results hitherto and devises future work.

2. THE AEROSPACE INDUSTRY IN MEXICO.

The high-tech aerospace industry sector involves processes that demand strict certifications from the corresponding international organizations; the jobs generated by this industry require high-level technical preparation; the manufacturing systems require processes involving precision mechanics, high-performance control systems, electronic products and sensors (avionics), as well as the use of material technology such as super alloys and composite materials. Although the aerospace sector has kept a low-profile in Mexico, it is highly active in the manufacturing of airship components and assemblies: approximately 77 suppliers exist (as third and fourth Tier suppliers), 12 of them have registered offices in the state (Nuevo León). Most of these manufacturers are U.S. firms

which have moved their operations to lower-cost centers, being this the earlier global-competition strategy that benefited the automotive industry in Mexico.

Currently, annual sales of aerospace exports from Mexico to the US represent a value of 150 million dollars. Despite these figures, the aerospace industry barely makes up 0.52% of the international export market. In the state Nuevo León, there are well-developed technological competitors in the automotive industry; however, a good opportunity has been detected in the aerospace industry that requires a more advanced technological level. On the other hand, the constant development of a knowledge-based society undoubtedly depends on generating, understanding and transferring new knowledge, as well as consolidating academic programs at Universities and focusing on innovation and research, all these leading to the disclosure of information through communication technologies and its use in new high-tech industry of manufactured goods and services.

As an educative institution, the ITESM is unique in this sense, scoping a wide range of the educational spectrum: research and the exploitation of its results to make the most out of technological advantages, and the development of researchers and professionals that contribute significantly to the regional and national development.

3. REVERSE ENGINEERING AS A TEACHING TECHNIQUE.

Reverse Engineering (RE) is already a main technique in a wide range of manufacturing processes. The RE approach focuses on the re-analysis of existing products where the relevant technical documentation or information is not available. The aim is to investigate specifications, cost, operations, manufacturability, reliability, limitations, function and other information of these products and their components in order to further develop a new, competitive product. RE can be applied to software as well as hardware products. As suggested in [9] and [10], this converse approach is important in a variety of manufacturing processes: ”the process of analyzing a subject system ... to identify the system’s components and to create representations of the system in another form or at a higher level of abstraction..”. Therefore, RE begins with a finished product and works backwards to recreate engineering concepts, analyzing the design of the system and the interrelationships of its components.

The purpose of employing an engineering technique typically used by the automotive industry could be best illustrated in the sense of benchmarking, for the installment of competitive study centers, for the development of new innovative products from cognitive exploration, from a cognitive objective, and therefore for cognitive processes with engineering techniques properly focused in education that could be of great advantage regarding teaching and learning engineering methods.

The main goals of this project can be stated as:

1. *Demonstrate the applicability of RE within a new educational model which emphasize learning through abstraction, experimentation and exploration, also incorporating more established techniques such as PBL and POL.*

2. *Develop techniques, methods and procedures for the assembly, design, manufacture, control and instrumentation of aircrafts, in a context of computational modeling of solids, analytical and numerical modeling of kinematics and kinetics and virtual modeling of real environments using the aforementioned techniques*.

Other specific goals are:

- To generate knowledge by the practical assembly of an experimental airplane.
- To develop complete, reliable, and fully detailed models describing the airplane behavior, as well as its parts and subsystems.
- To perform experimental testing to assemblies and sub-assemblies of the aircraft
- To develop specifications, methods and procedures for manufacturing aircraft components.

Regarding the ITESM mission, the authors believe that the new educational model proposed here strongly contributes to the development of responsible citizens and leaders who will promote competencies and strengths in several fields. In particular, they will:

- Identify and propose solutions to real problems in the Aerospace field with the adequate use of human, technological, and economic resources.
- Participate in the generation of ideas oriented to the implementation of improvements in the work-team.
- Promote the observation, analysis, and analogy in the practical application of knowledge.
- Interrelate efficiently and cordially with every member of the work-team, via assertive oral and written skills, active listening and a thorough understanding of specialized technical language.
- Integrate in all levels of the working environment.
- Assume an ethical attitude and behavior when executing and reporting their activities.
- Adapt to the cultural diversity in the groups and organizations.
- Participate in the sustainable development of the country and its communities, focusing on innovation, technological development and competitiveness in his/her area of expertise, in this case Aeronautics Engineering.

Several Engineering subjects have been identified in our project, those being: Assembly, Structural Analysis, Aerodynamics, Instrumentation, Documentation,

Conceptual Design, Instrumentation, Human-Machine Interaction and Control and Digital manufacturing (PLM Aeronautics). Each field has specific goals described in the following paragraphs.

- **Assembly:** Execute a complete assembly of an RV-10 airplane, following a manufacturing process according to AS9100 standard specifications, with stock control, operative skills development and fabrication process representation by software-simulation. Acquire the know-how of fundamental manufacturing operations of airplanes, in particular, structural parts assembly. To use typical hardware, manufacturing and handling of aero-parts. To learn handling operations for aluminium sheets specifically for aircraft structures.
- **Structural Analysis:** Develop and analyze a complete computational model of an RV-10 airplane structure by imposing typical working loads. Analyze and validate the structure of the airplane in critical points submitted by typical flight cases. Study the structural dynamic and fatigue behavior of airplane structures doing experimental testing validation.
- **Aerodynamics:** Perform analytical studies of airplane aerodynamics, focused in the RV10, including the basic physics principles that govern fluid flow through the airplane surface. To elaborate experimental testings in wind tunnel to corroborate computer models.
- **Instrumentation:** Study, analyze and understand the function and usefulness of basic electronic devices used on airplanes to monitor, supervise and control the aircraft. Design, build and test prototypes of specific electronic and control devices.
- **Human-Machine Interaction and Control:** Develop and test an electronic control system for vertical and horizontal stabilizers of RV10 airplane, complying with ergonomic characteristics, reaction time and airplane action.
- **Conceptual Design:** Develop and test design concepts for the different elements comprising of the RV-10 airplane cockpit using the pilot's experience while interacting with the airplane.
- **Digital manufacturing (PLM Aeronautics)**: Develop virtual manufacturing models of assembly and manufacturing operations where students apply Product Life Cycle Management (PLM) concept to the empennage of the RV10.

Since this project requires special skills, great emphasis must be done, to carefully select students that will be participating in this program.
Notice that, our university does not have a special track in Aerospace/Aeronautics Engineering. Fifty prospective students applied to the project and only twenty students were enrolled in the different field projects.

The student profiles for this project were as follows:

- Mechanical or Mecatronics Engineering Students (third year and up)
- Interest in how various mechanical devices or principles operate,

- Technical skills (inspecting, repairing, installing, troubleshooting, machine tools, etc.).
- Good communication and team work skills.
- Good technical background in analytical and experimental subjects, in particular for those students who are enrolled on Aerodynamics and Structural Analysis problems.

Although the RV-10 project is a capstone, it will gather experience and knowledge aimed at establishing similar projects for students on their third year and up. These projects will help them posing an open problem in terms of manageable pieces, as well as developing alternative solutions and synthesize previous and new knowledge for innovative results, which can be implemented in the construction of a new prototype. The students are expected to dedicate at least eight hours per week during 16 weeks (equivalent to 3 US credits or 5 ECTS). Eventually, the student could register for a second course towards application projects, which could last for a year.

As an example, the Figure 1 shows a typical flow process developed during this project. For the particular case of the Structural Analysis subject, the students learn to examine the empennage structure and measure of the empennage parts. The CAD/CAE software has been used for this purpose. Some abilities of modeling solids and FEM analysis have been learned during the project and allow the students to apply RE techniques by examining and dissecting the airplane. This is to encourage conceptual abstraction in the students to abstract, as well as to gather theoretical and practical engineering comprehension, both fields required for a successful product development/innovation. During the project the technical documentation is a crucial task to be completed. In this case, the students learned to manage a professional Editor for this purpose based on AS9100 Regulations.

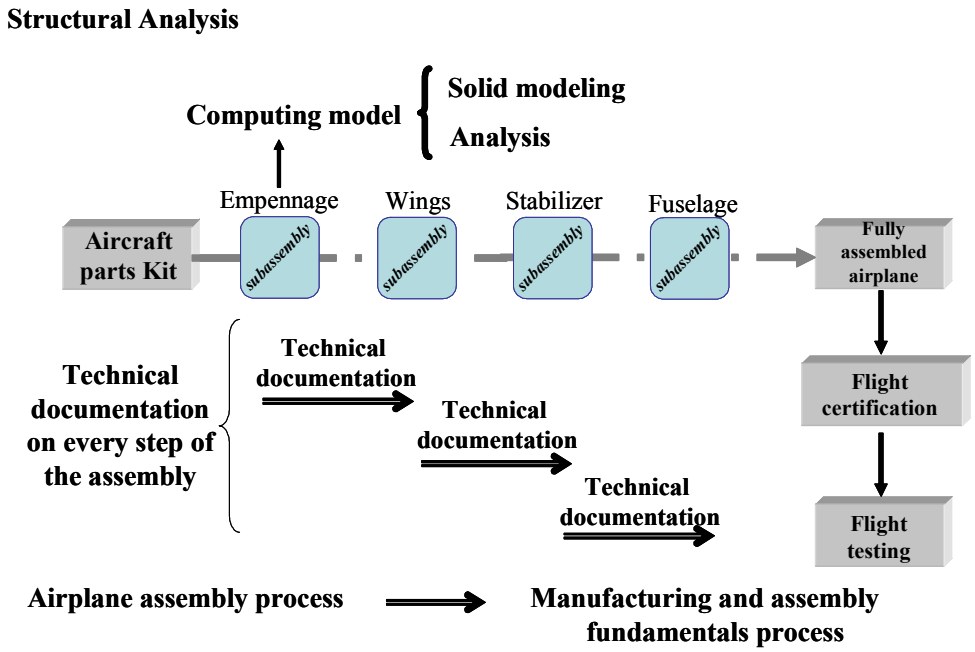

Figure 1.- Flow Diagram for Structural Analysis Case

4. STUDENTS PROJECT RESULTS ACHIVMENTS

Some results achieved in the 2005 Fall semester on particular subjects are described following.

.

The dimensional measuring of all the empennage components was entirety achieved before any assembly. Students were trained in the CAD/CAE software (UGS and Hypermesh). Materials research dealing with the aluminium alloys used on structural parts of the airpcraft which have small expansion coefficients subjected to thermal changes which reduce the tension and shear stresses on the rivets.
Neglect the rivet holes and place the properties of the weakest direction of the thin plate.
Figure 2 shows solid modelling and FEA analysis of some components.
In the fall semester students had the opportunity to be trained in basic sheet metal operations that help them assembling the empennage.
The assembly of empennage has been completed, in figure 3 shows some of the components been assembled.

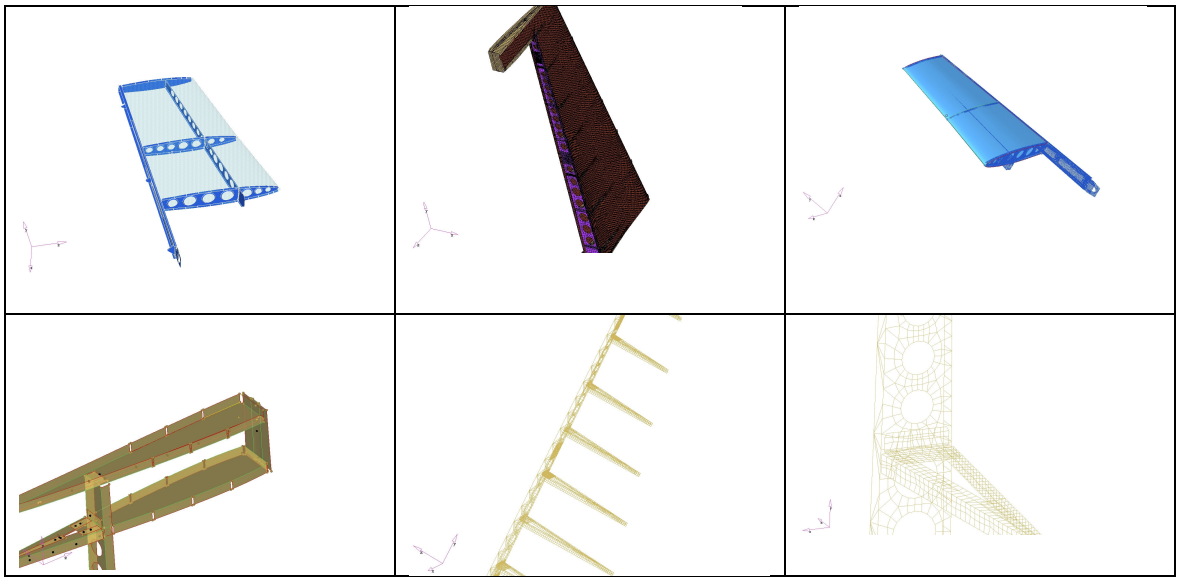

Figure 2.CAD models for some of the empennage parts

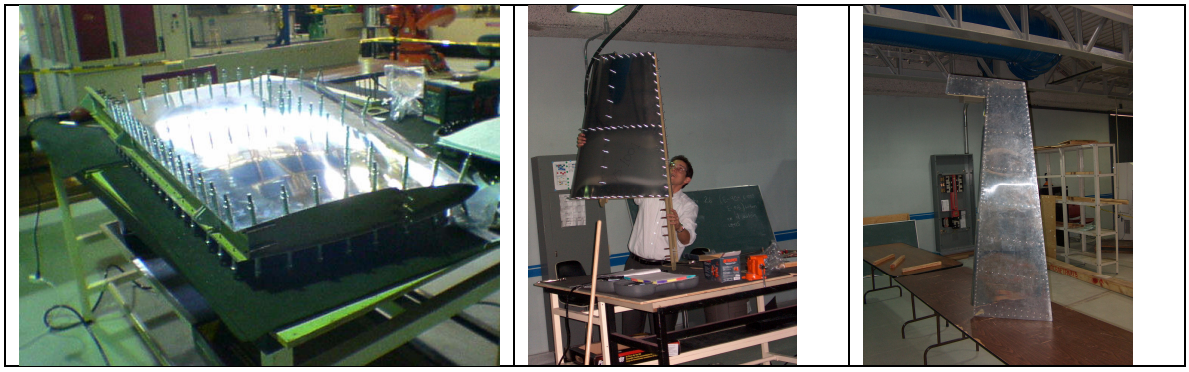

Figure 3. Some sub-assemblies of the empennage developed during the fall-semester 2005.

5. LESSONS LEARNED

The experience of development Reverse Engineering project has provided valuable lessons for students, faculty and engineers from the company involved. The first phase of the project execution has taught us a great deal. Several lessons are summarized here.

Project Management. Coordinating people, tasks and materials proved to be complex, and a good project management is crucial. In this project where different parts or components have to be use by various teams to perform different reverse engineering task or activities is critical, since one depend the others.

Teamwork Skills. Our students have developed teamwork skills thru all the curriculum, leadership, abilities to organize their teamwork from the start to the end, time and resource management, team roles and organization. All these are factors that influence in the results and performance of the team.

Communication The generation of reports and the administration of flow information through the duration of the project must be improved, since some tasks were redundant. The coordination between the different work-teams is an issue that has to be taken into account also, and the continuous update of the project status and significant information in an Internet Share Point.

Technical Documentation The documentation initially was written in conventional word processor, as a consequence not all the information was documented in Epic Editor Software, it is then necessary to establish the mandatory use of this Documentation Software for the students involved in the project. A knowledge management strategy must be also established for the documentation of new ideas, the capture of the learning experiences, and tracking the decision making process during the project.

Sheet Metal Training It was necessary to train the students in basic manufacturing and handling operations related to aircraft manufacturing, since this is not including the Mechanical Engineering curriculum.

Software Skills: As the project was develop, more complex skils are needed in software tools as CAD/CAM/CAE(Unigraphics NX, Hypermesh, Fluent, etc.) by the students, and training time is required to develop these skills.

5.1 ABET CRITERIA AND ITS RELATION WITH THE PROJECT.

One of the biggest concerns of the ITESM Campus Monterrey is the ability to evaluate the quality of its academic programs and to have certainty that they fulfill the requirements that are made in comparison with other programs in the world. The series of dizzying scientific and technological changes combined with new social and political conditions impose the need to reformulate effective educational models. In particular, the field of engineering is proposed for the development of perspectives of educational transformation in the sense of curricular flexibility and the formation of professional competencies.

At the ITESM Campus Monterrey, we assume the importance of viewing ourselves in the global context of engineering instruction, and thus we consider it fundamental to have as reference “Engineering Criteria 2006-2007" by the Accreditation Board for Engineering and Technology (ABET) that will be implemented as a norm for

accreditation, and in our country this will be done by means of the Inter-institutional Committee for Superior Evaluation (CIEES) and by the Accreditation Council of Engineering Instruction (CACEI). In order to comply with this accreditation, ITESM Campus Monterrey must demonstrate that their graduates possess a firm knowledge of science (physics, mathematics, chemistry) and the fundamentals of engineering. They should also possess the abilities of communication, multidisciplinary work in teams, and the ability of lifelong learning, along with a consciousness of the social and ethical problems associated with their profession. We are considering, to comply with the ABET accreditation objectives.

6. SUMMARY.

The implementation of Reverse Engineering (RE) techniques represents a significant challenge towards re-designing the educational environment at the ITESM. Project developments so far have convinced the authors about the usefulness of this exciting learning tool.

The students were highly motivated and displayed the ability of managing multiple tasks simultaneously. They also showed good resources and creativity in developing solutions complying with the project objectives.

This project has been a great opportunity to experience up- and downsides of the student work, normally not available in traditional courses.

A main point manifested by the students was the opportunity to manage different aspects of a project, including project management, technical documentation, quality, engineering, etc.

The RV-10 airplane will have to comply with trough the whole process of certification in order to fly. This project will implement the scientific methodology of Reverse Engineering from its early stages is only about assembly.

Enterprise involvement is relevant and must be remarked in this project.

While RV-10 is a small airplane, the control systems and avionics knowledge contains all the generalities found in more complex or larger commercial aircrafts.

A structured-systematical methodology of the assembly of the RV-10 aircraft has been developed, as specified in the Aeronautic Regulations.

BIBLIOGRAPHY

1. Martin M., 2002. *El Modelo Educativo del Tecnológico de Monterrey ITESM Technical Report. Internal and Institutional Publication of Monterrey Tech.*

2. Morales-Menéndez R., Ramírez-Mendoza Ricardo A., and Limón-Robles J. *Experimental Techtronic's Education at Monterrey Tech. Fifth international workshop on Active Learning in Engineering Education. Delft-Amsterdam, June 8-11, 2005, Netherland.*
3. Morales-Menéndez Rubén, Ramírez-Mendoza Ricardo A. and Jorge Limón-Robles. *Educational Technology at Monterrey Tech. The Eighth IASTED International Conference on Computers and Advanced Technology in Education, August 29-31, 2005, Oranjestad, Aruba.*
4. Grimheden M. and M Hanson. *How might education in mechatronics benefit from problem based learning. 4th International Workshop on Research and Education in Mechatronics 2003, Bochum, Germany.*
5. Van's Aircraft, Inc., ©2005, *http://www.vansaircraft.com/public/rv-10int.htm.*
6. Wood, Kristin L, Jensen, Daniel, Bezdek, Joseph, Otto, Kevin, "Reverse Engineering and Redesign: Courses to Incrementally and Systematically Teach Design". *Journal of Engineering Education. Journal of Engineering Education, Jul 2001. 90, 3; pg. 363.*
7. Baxter Ira D., Mehlich M. "Reverse Engineering is Reverse Forward Engineering", *Proceedings of the Fourth Working Conference on Reverse Engineering, October 6-8, 1997, Amsterdam, the Netherlands, IEEE Computer Society Press (1997).*
8. Knox, R.C., et al., *"A Practitioner-Educator Partnership for Teaching Engineering Design," Journal o(Engineering Education, vol. 84, no. 1, Jan., 1995, p. 5.*
9. S.W. Kim et al., "Reverse engineering: high-speed digitization of free-form surfaces by phase shifting grating projection moire", *International Journal Machine Tools & Manufacturing, 39, (1999), pp. 389-401.*
10. *R. Arnold: Software Reengineering, IEEE Computer Science Press 1993.*
11. E. Chikofsky, *"The Necessity of Data Reverse Engineering," Data Reverse Engineering: Slaying the Legacy Dragon, P. Aiken, Editor, McGraw-Hill, Inc., New York (1996), pp. 8-11.*
12. *Criteria for Accrediting Programs in Engineering in the United States, Engineering Accreditation Commission, Accreditation Board for Engineering and Technology, Inc., New York, N.Y., Effective for Evaluations During the 1994-1995 Accreditation Cycle; replaced by ABET 2000.*
13. Mohamad Saleh. *Reverse Engineering An effective approach to studying Mechatronics at undergraduate tertiary education. ICIT 2003 –IEEE, 2003. Maribor. Slovenia. Pg.824-829.*
14. Klaus Bothe. *Reverse Engineering: the Challenge of Large-scale Real-World Educational Projects. 115-126. CSEE&T, Electronic Edition (IEEE Computer Society DL) Pp. 115-126.¨*
15. *CRITERIA FOR ACCREDITING ENGINEERING PROGRAMS. Effective for Evaluations During the 2006-2007 Accreditation Cycle Incorporates all changes approved by the ABET. Board of Directors as of October 29, 2005. ABET, Inc. 111 Market Place, Suite 1050. Baltimore, MD 21202.*