An Educational Design Process for Different Capstone Classes

Mohamed El-Sayed

Department of Mechanical Engineering
Kettering University, Flint, MI 48504

Abstract

Capstone design classes are usually structured around teamwork and an open-ended design project. For Mechanical Engineering Departments with several specialties, several capstone classes are usually offered. To achieve the program learning objectives and outcomes across the different specialty, the need for a common educational capstone design process arises.

In this paper a common educational capstone design process that parallels that of leading corporations and can be followed across different capstone classes with application to machine design and automotive capstone classes is presented. The developed process fosters creativity, develops students' communication skills and provides a logical product realization engineering/management experience.

The educational design process starts with team building and brainstorming focusing on creativity as right brain activity. From the brainstorming list of projects one is selected based on creativity, effort and timing. Each team proceeds to develop a written and oral proposal containing product history, state of the art, Bill of Product, development and simulation methodology, project management/impacts and cost estimates. The Bill of Product represents the set of product attributes from which design criteria and engineering targets are derived.

The proposal and project management chart become the road map for tracking until completion. Design construction, analysis and simulation, safety, ethics, social and political implications to design decisions are lectured on until the Bill of Materials is populated for the progress report and presentation. Students are then lectured on design synthesis/validation, quality, manufacturability and variations until the Bill of Process is developed for the final report and presentation.

Introduction

Capstone design classes for Mechanical Engineering students usually entail one open-ended design project. For Mechanical Engineering Departments with several specialties, such as the case at Kettering University, several capstone classes are usually offered. To achieve the program learning objectives and outcomes across the different specialty, the need for a common educational capstone design process arises.

A common educational capstone design process should address several needs. First, it should provide student with a comprehensive and realistic product realization engineering/management experience that represents real life in different engineering settings. Second, it should meet and exceed the global learning educational objectives for any capstone level design class. Finally, it should be modular and applicable to any capstone class independent of the design project type.

In this paper a common educational capstone design process that parallels that of leading corporations and can be followed across different capstone classes with application to machine design and automotive capstone classes is presented. The developed process fosters creativity, develops students' communication skills and provides a logical product realization engineering/management experience. Another advantage of the developed process is the ability to fit different length of school terms. Due to the co-op program at Kettering University the class term is eleven weeks. The developed process was fitted to the eleven weeks timing with two 120 minutes sessions per week.

Process Educational Objectives

To provide students with a comprehensive and realistic product realization engineering/management experience and be applicable to any capstone class, the following are the main preset educational objectives of the developed process:

Objective 1: Creative thinking in design

1.1 Students will be able to brainstorm and think creatively to achieve alternate design solutions.

Objective 2: Teamwork and communication skills

2.1 Students will be able to form teams and work effectively with others to achieve design goals.

2.2 Student will be able to present their ideas, plans and design alternatives in written and oral formats.

Objective 3: Project planning and management

3.1 Student will be able to use project's planning tools to plan tasks, timing and coordinate design activities.

Objective 4: Identify product attributes and design criteria.

4.1 Student will be able to use systematic design process thinking to analyze the conceptualized product attributes and transfer these attributes to design criteria and engineering targets

Objective 5: Product simulation and synthesis

5.1 Student will be able to apply their education to simulate the conceptualized product in the intended environment and synthesize to achieve targets and attributes.

Prerequisites and skills:

For the effective and successful implementation of the process in capstone classes, students should have the following, standing, skills, and prerequisites:

1. Senior Standing
2. CAD Skills
3. Analysis and simulation Skills
4. Design of Mechanical Elements
5. Basic computer skills

Educational Design Process Flow

Due to the co-op program at Kettering University the class term is eleven weeks. The developed process was fitted to the eleven weeks timing, with two 120 minutes sessions per week. Meeting the requirement of eleven week term demonstrates the ability of the developed process to fit lengthier school terms easily.

Starting with week one lectures on team dynamics and team formations criteria are conducted. Students select their teams based on the laid out criteria, with the following two main objectives:

1. Ability to work together
2. Technically complement each other

After forming teams students are then lectured on brain storming skills and creativity as right brain activity on individual and team level. The key for successful brain storming sessions is to suspend judgment and allow creative ideas to flow. By practicing brain storming students prepare a list of potential projects. From the list of projects one is selected based on the following criteria:

1. Originality and creativity
2. Enough work for all the team members
3. Ability to deliver desired results within class time frame.

During the second and third weeks students are lectured on the design process, project selection and planning, bill of product, product attributes, project management, proposal writing and presentation. The lecturing continues on relating the product attributes to design criteria, engineering targets. This culminates into the proposal development and delivery at the end of the third week of class.

The proposal developed by each team with the project management chart becomes the road map for the team to the end of term. Design construction, design development and simulation methodology, analytical simulation, design synthesis and optimization, safety, ethics, social and political implications to design decisions are lectured on during week four to week seven. The design construction, analysis and simulation work are developed during these four weeks. The Bill of Materials is populated during the four weeks for the progress report at the end of week seven.

From week seven to eleven student are lectured on Manufacturability, Bill of process development, variation, quality, reliability, product life cycle, and design validation. During this period the Bill of Process is developed, populated and design project is finalized. These activities culminate into the final report and presentation during the eleventh week.

The educational design process flow diagram is presented in Figure 1, and the main topics covered for each class period are presented in Table 1. The duration and coverage depth for each topic can be expanded for school terms with more than eleven weeks.

As shown by the developed capstone educational process flow diagram, the process is tailored around an industrial based design process. The educational process starts by covering an important but absent aspect of engineering education. This aspect is the relationship between engineering requirements or targets and the desired final product and its attributes. The flow down of attributes defined in the end user domain to design criteria defined in the engineering domain from which a set of targets are derived for analysis and simulation is the key for any successful product design and educational efforts.

After identifying the target for each attribute and ranking these targets according to preset priority for each attribute the design construction, simulation, synthesis and optimization can be performed. The success in this stage hinges on the ability to perform representative virtual or physical simulations and choose the proper design alternative to achieve the desired attributes within the priority structure.

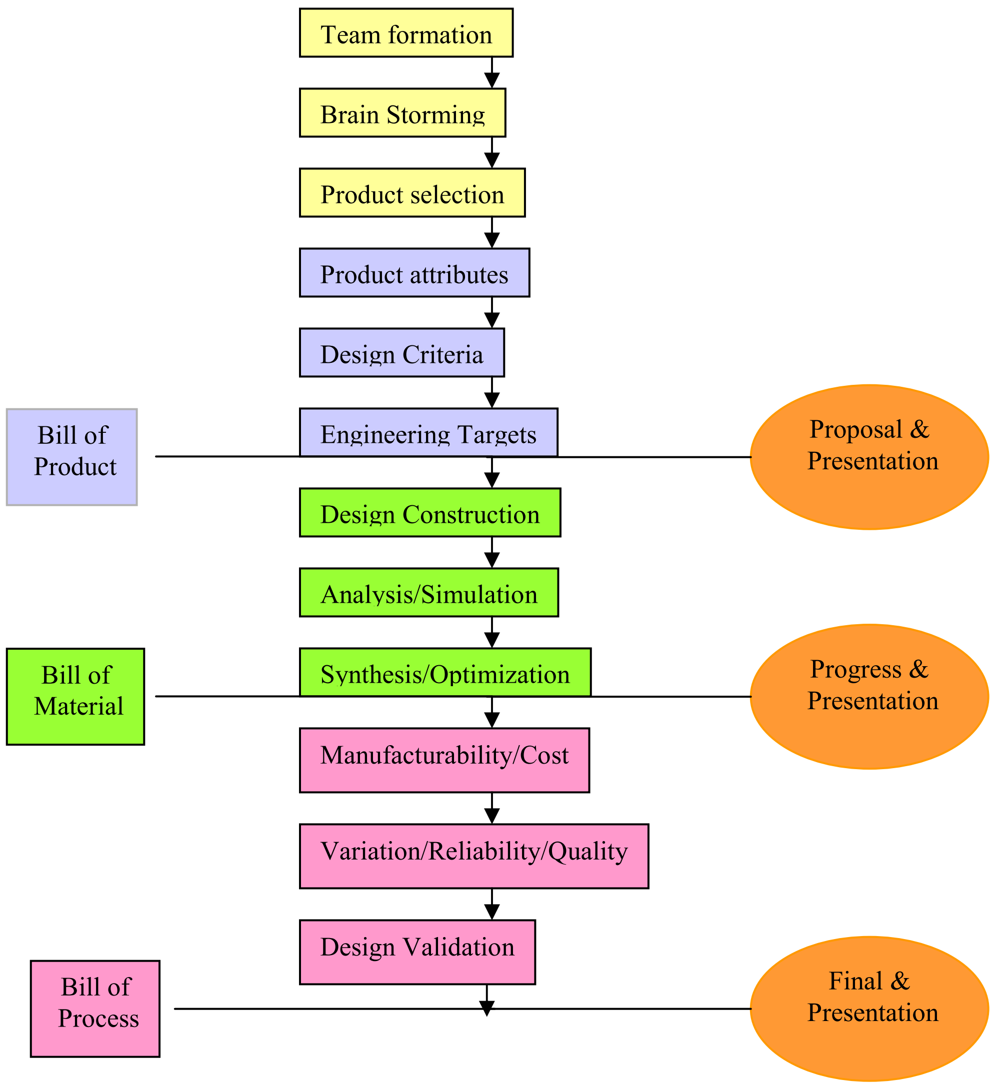


Figure 1: Educational Design Process Flow Diagram

Topics covered:

Week	Topic
1	Team formation and working in teams
	Brainstorming and creativity in design
2	The engineering design process and Project selection
	Project planning and Proposal writing
3	Product attributes (bill of product), design criteria and engineering targets
	Written proposal and in class presentations delivered
4	Project management and bill of materials development
	Design construction
5	Product virtual and physical Simulations/Analysis
	Design analysis, synthesis and optimization
6	Progress reports and presentation preparation
	Alternative Designs selection
7	Ethical, social and political implications of engineering design decisions
	Progress reports and in class presentations delivered
8	Manufacturability and Bill of process development
	Cost analysis and minimization
9	Product and manufacturing variations
	Product quality and reliability
10	Product life cycle, maintainability and serviceability considerations
	Final reports and presentation preparation
11	Design validation
	Final reports and in class presentations delivered

Table 1: Eleven weeks-Two sessions of 120 minutes per week

Process Application Examples

The developed process has been successfully used for machine design capstone and automotive design capstone classes over several years at Kettering University. It provided a structured approach to project management and product design while allowing student to find creative solutions to their design problems. It allowed students to use off the shelve technologies to focus their efforts on the needed component and simulations to achieve the desired product attributes. In the following selected deliverables of two capstone projects are presented to demonstrate the application of the process in a machine design capstone class and automotive design capstone class.

1. Machine Design Capstone Example:

The Ultimate ZX2002 Billiards Gaming Systems

Proposed Project/Objectives

- Automated Precision Racking System
- Automated Cleaning System
- Digital Interface w/ Multiple Game play Modes
- Automatic Cue Chalking System
- Ball Position System (BPS)
- Laser Technology for Shot Advice
- Multiple Lighting Arrays

Attributes

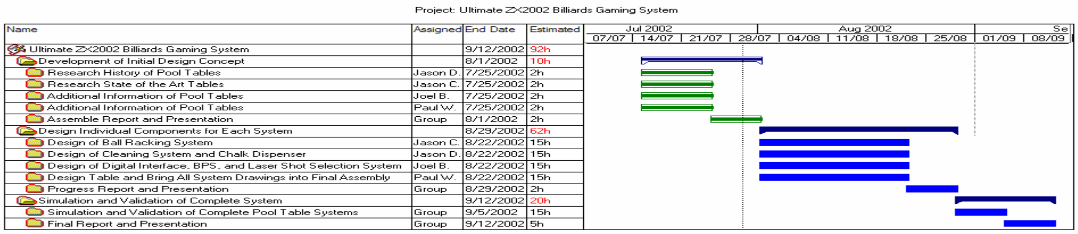
- Quality
- Top-Notch Performance
- Aesthetic Visual Appearance
- Durable
- Intelligent

Design Criteria

- 50” x 100” Playing Surface
- Precision Machined Slate
- Regulation Felt
- Oak Frame Utilizing Dovetail Joints
- BPS System w/ Top Electronic Components
- Max. Weight: 1000 lbs.
- Min. Lifetime: 25 years

Technical Requirements

- Structure: 27,000 lbs at 0.03” Deflection
- Slate: 0.01” Flatness
- Canvas: Proper Weave and Weight
- BPS: Location to within 0.01” Accuracy
- Vacuum System: Capable of Cleaning all Angles of Playing Surface



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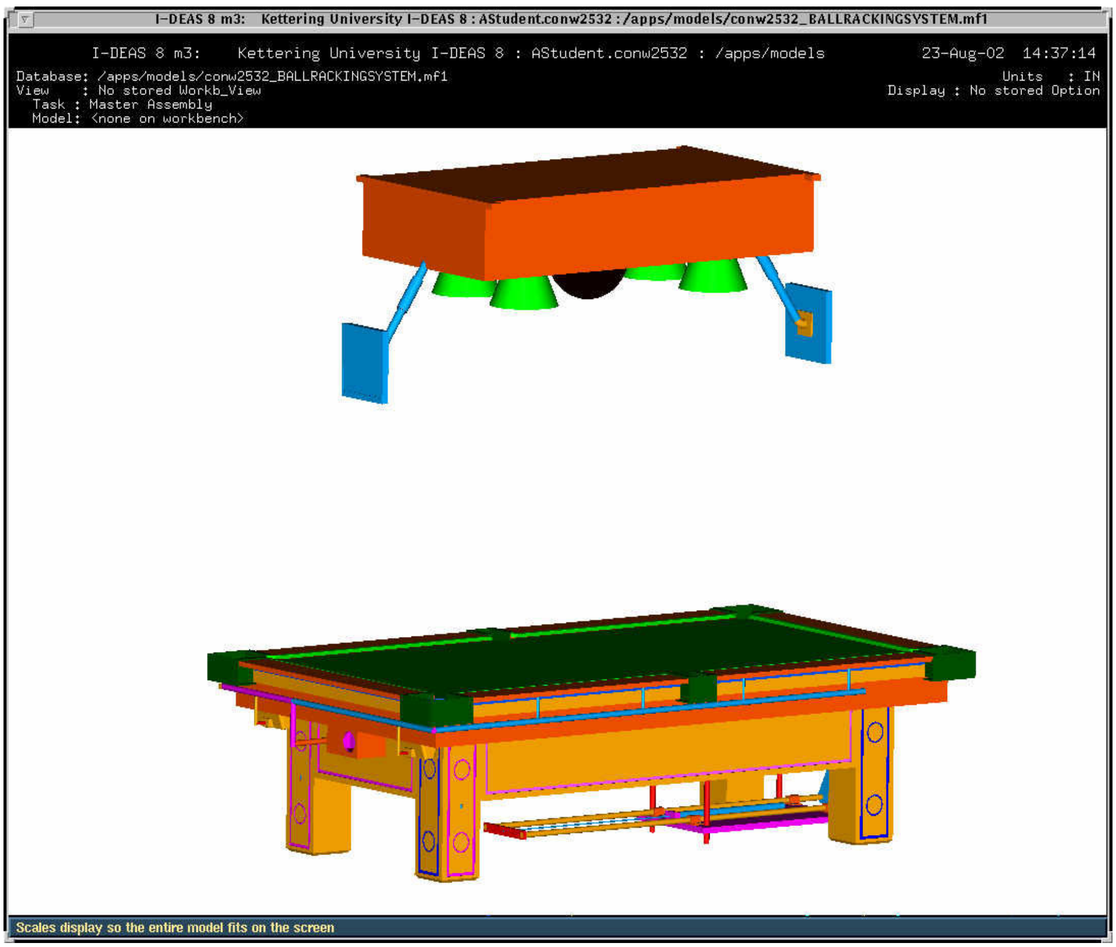


The Ultimate ZX2002 Billiards Gaming Systems

2. Automotive Design Capstone Example:

<u>Luxury Executive – 'LEX'</u>

ATTRIBUTES

The attributes intended to appeal to the consumer are listed below:

- Comfortable and quite ride.
- Easy and economical to maintain and operate.
- Powerful and responsive feel.
- Convertible top.
- Good gas mileage.
- Comfortable, user-friendly interior.

DESIGN CRITERIA

- Comfortable and quite ride = Rigid body with low noise, vibration, and harshness.
- Easy and economical to maintain and operate = Oil change intervals over the average 4,000 miles and the first scheduled tune-up well into the life of the car.
- Powerful and responsive feel = High output engine with good skid pad performance.
- Convertible top = Retractable hardtop.
- Good gas mileage = High tech engine and transmission.
- Comfortable, user-friendly interior = Ergonomics.

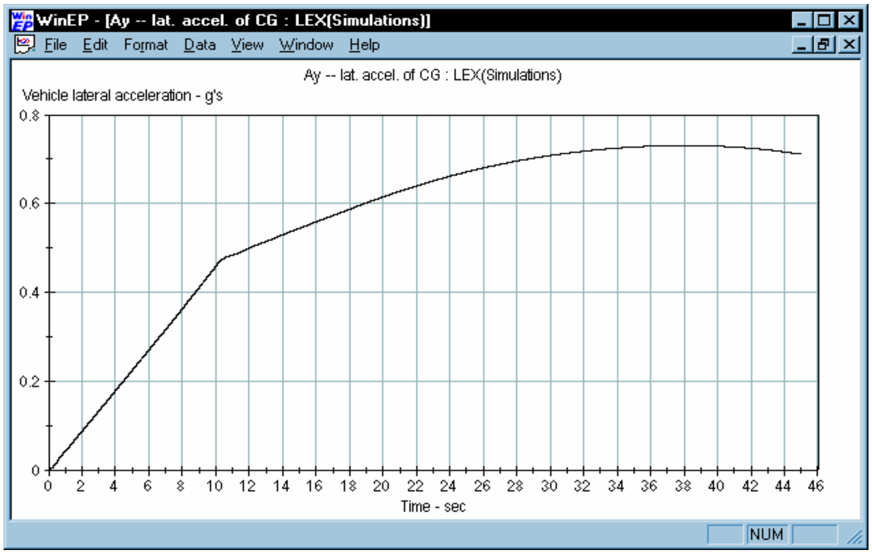
ENGINEERING TARGETS

- Rigid body with low noise, vibration, and harshness = Built on Lincoln Town Car Cartier L Chassis with body on frame design
- Oil change intervals over the average 3,000 miles and the first scheduled tune-up well into the life of the car = Oil change intervals at 4,000 miles and the first scheduled tune-up not until 100,000 miles.
- High output engine with good skid pad performance = 4.8L 270 horsepower engine and 0.80 g's on the skid pad.
- Retractable hard top = Less exterior noise while still having a convertible
- High tech engine and transmission = "Displacement on Demand" engine and Six-Speed Automatic Transmission.
- Ergonomic interior = Gauges within easy view of the driver and the controls are in easy reach. Comfortable and adjustable seating to fit the passengers.

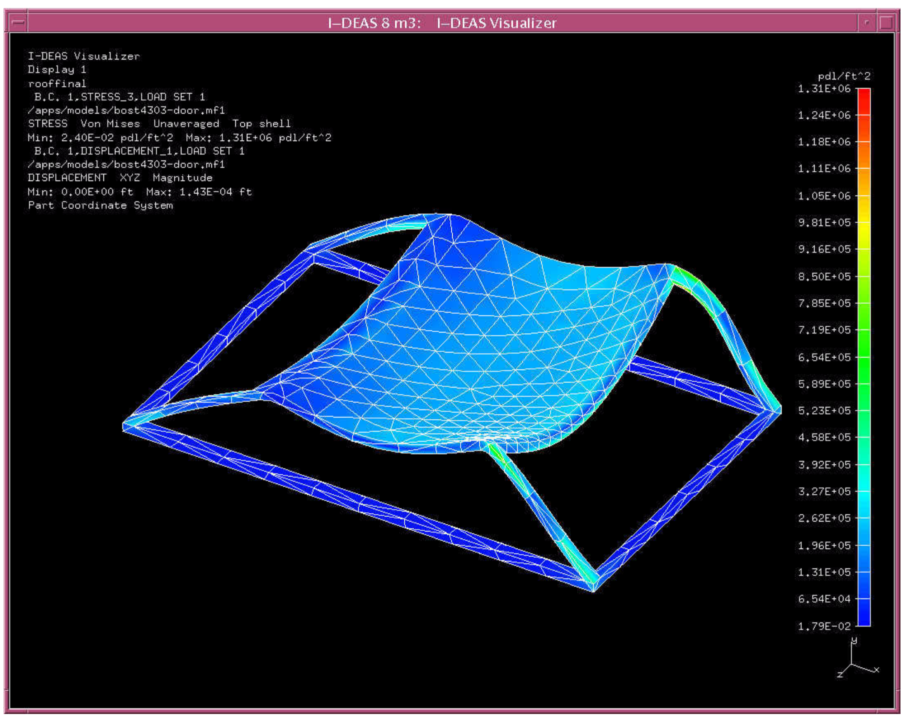
BILL OF MATERIAL

Qty'	Subsystem	Part Number	Design Criteria	Engineering Targets	Source	Simulation	Cost	Status: Time	Status: Targets
Body									
2	Front Door	B-0001	Stiff Body with Excellent Saftey Ratings	Coefficient of Drag Less Than 0.35.	Lincoln OEM	Clay Model	200	Completed	
2	Rear Suicide Doors	B-0002			Lincoln OEM		200		
2	Front Fenders	B-0003			Lincoln OEM		250		
2	Rear Quarter Panels	B-0004			Lincoln OEM		250		
1	Retractable Hardtop	B-0005			Lincoln OEM		1250		
2	Rocker Panels	B-0006			Lincoln OEM		75		
1	Hood	B-0007			Lincoln OEM		400		
1	Deck Lid	B-0008			Lincoln OEM		350		
2	Headlights	B-0009			Lincoln OEM		100		
2	Tail Lights	B-0010			Lincoln OEM		100		
1	Grill	B-0011			Lincoln OEM		300		
2	Front Fascia	B-0012			Lincoln OEM		300		
2	Rear Fascia	B-0013			Lincoln OEM		300		
1	Windshield	B-0014			Lincoln OEM		500		
1	Rear Window	B-0015			Lincoln OEM		300		
2	Front Door Windows	B-0016			Lincoln OEM		200		
2	Rear Door Windows	B-0017			Lincoln OEM		150		
2	Front Wheel well Inserts	B-0018			Lincoln OEM		65		
2	Rear Wheel Well Inserts	B-0019			Lincoln OEM		65		
1	Floor Pan	B-0020			Lincoln OEM		1000		
1	Firewall	B-0021			Lincoln OEM		750		
1	Trunk Pan	B-0022			Lincoln OEM		500		
1	Body Assembly	BS-0001				**Total Cost for Body**	7605		
Engine									
1	4807 CC Vortec V8	E-0001	Displacement on Demand, Good Fuel Economy	Engine can run as a V8 or a V4. 20/30 mpg	GM	Advisor	2250	Completed	
1	Transmission	E-0002			Ford OEM		1500		
1	Rear Differential	E-0003			Ford OEM		750		
1	Drive Shaft	E-0004			Ford OEM		100		
1	Electronics	ES-0002			Ford OEM		1000		
1	Powertrain Assembly	ES-0001				**Total Cost for Engine**	5600		
Chassis									
1	Frame	C-0001	Good handling for a large car yet still has a smooth ride	Over 0.8 Lateral g's.	Ford	CarSIM	1000	Completed	
2	Front Springs	C-0002		Less then 4.5° pitch and less then 3° roll at 60 mph	Eibach		250		
2	Rear Springs	C-0003			Eibach		250		
1	Front Suspension	C-0004			Ford		500		
1	Rear Suspension	C-0005			Ford		500		
4	Wheels	C-0006			Center Line		175		
4	Tires	C-0007			GoodYear		110		
1	Chassis Assembly	CS-0001				**Total Cost for Chassis**	2785		
Interior									
1	Driver Seat	I-0001	Refined, Polished, & Comfortable. Great Sound. Automatic Controls	Leather & Wood Trim, 10 Speakers with a 320 Watt Amp. 8-way Power adjustable seats	Jaguar OEM	Paint Shop Pro	800	Completed	
1	Passanger Seat	I-0002			Jaguar OEM		800		
1	Split Rear Bench	I-0003			Jaguar OEM		1200		
1	Radio	I-0004			Alpine		3000		
1	Nav System/DVD	I-0005			Alpine				
10	Speakers	I-0006			Alpine				
3	Mini Screens	I-0007			ProScan		1200		
N/A	Wood Trim	I-0008			Jaguar OEM		300		
1	Computer	I-0009			Dell		1500		
1	Interior Assembly	IS-0001				**Total Cost for Interior**	8800		

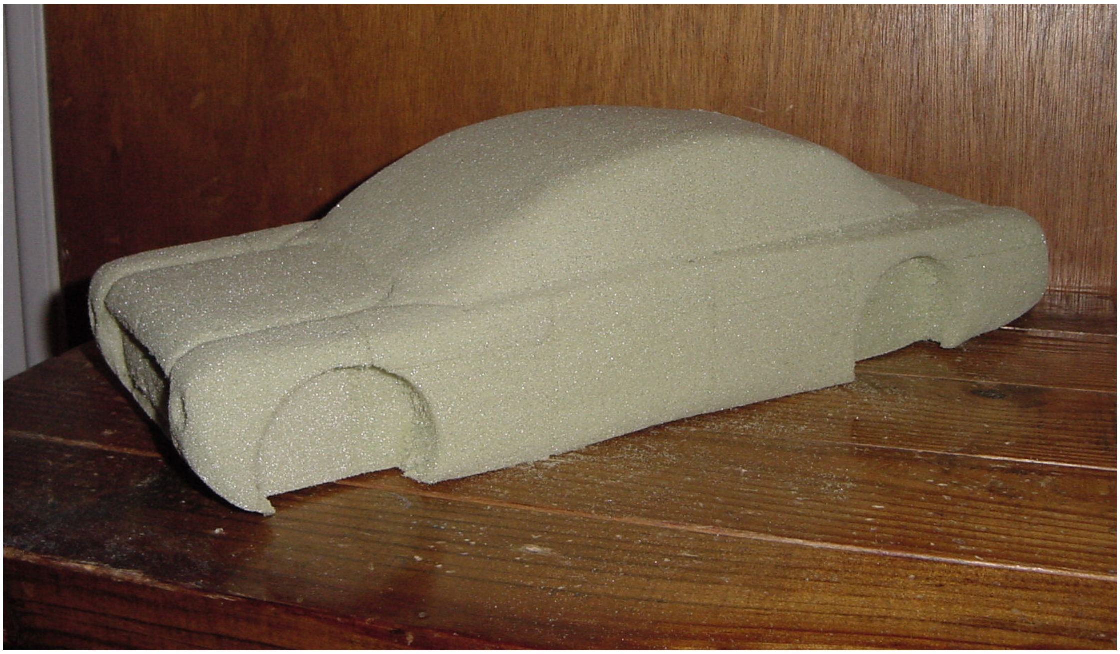
SIMULATION & METHODOLOGY



Lateral Acceleration “LEX”

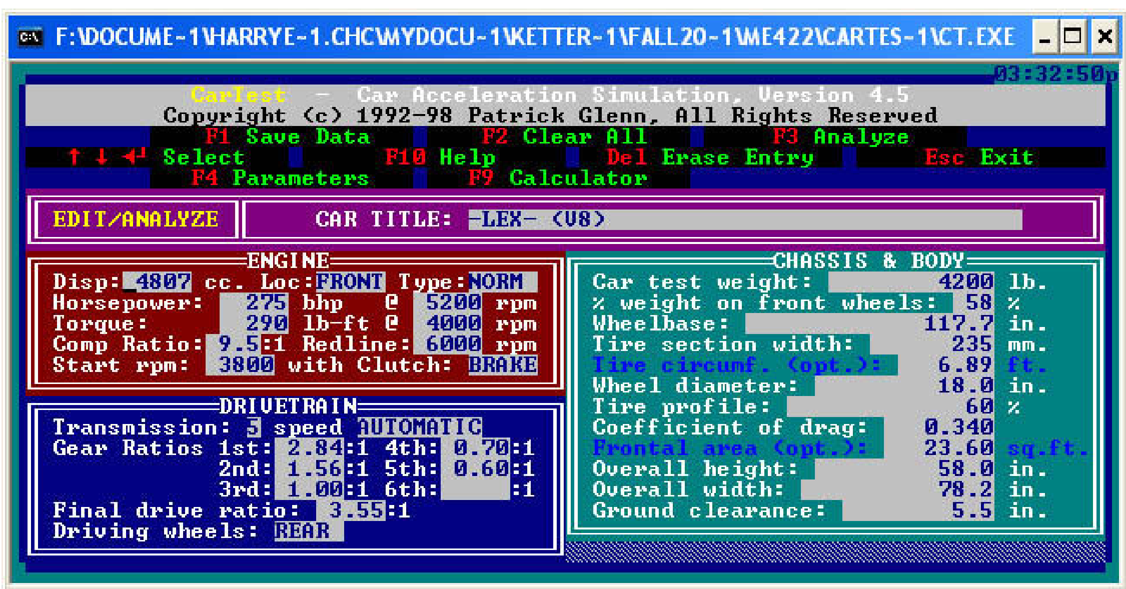


Carbon Fiber Roof Crush FEA



Foam Model of the LEX Front View

ENGINE ANALYSIS



V8 Engine Model

V8 Fuel Economy

BILL OF PROCESS

Bill of Process

Subsytem	Part #	Source	Manufacturing Process	Finish	Assembley Sequence	Fastner	Fits & Tolerene
Body							
Front Door	B-0001	Lincoln OEM	Sheet Metal Stamping	Paint & Clear	1. Mount Floorpan to Frame 2. Install Firewall 3. Mount Rocker Panels 4. Mount Fenders and Quarters 5. Install Lights into Fascias 6. Install Front and Rear Fascias 7. Install Trunk Pan 8. Install Doors 9. Install Hood and Deck Lid 10. Install Glass and Grill	Bolts and Welds	Standard Ford tolerances for automotive bodies
Rear Suicide Doors	B-0002	Lincoln OEM					
Front Fenders	B-0003	Lincoln OEM					
Rear Quarter Panels	B-0004	Lincoln OEM					
Retractable Hardtop	B-0005	Lincoln OEM					
Rocker Panels	B-0006	Lincoln OEM					
Hood	B-0007	Lincoln OEM					
Deck Lid	B-0008	Lincoln OEM					
Headlights	B-0009	Lincoln OEM	Standard Process for Lights				
Tail Lights	B-0010	Lincoln OEM					
Grill	B-0011	Lincoln OEM		Chrome			
Front Fascia	B-0012	Lincoln OEM	Sheet metal stamping	Paint & Clear			
Rear Fascia	B-0013	Lincoln OEM					
Windshield	B-0014	Lincoln OEM	Obtain from Vendor	N/A			
Rear Window	B-0015	Lincoln OEM					
Front Door Windows	B-0016	Lincoln OEM					
Rear Door Windows	B-0017	Lincoln OEM					
Front Wheel well Inserts	B-0018	Lincoln OEM	Sheet Metal Stamping	Rust Protection			
Rear Wheel Well Inserts	B-0019	Lincoln OEM					
Floor Pan	B-0020	Lincoln OEM					
Firewall	B-0021	Lincoln OEM					
Trunk Pan	B-0022	Lincoln OEM		Paint & Clear			
Engine							
4807 CC Vortec V8	E-0001	GM	Done by GM				
Transmission	E-0002	Ford OEM	Manufactured and assembled same as Lincoln Towncar Powertrain only replace standard 4.6L engine with part number E-0001				
Rear Differential	E-0003	Ford OEM					
Drive Shaft	E-0004	Ford OEM					
Electronics	ES-0002	Ford OEM					
Chassis							
Frame	C-0001	Ford OEM	Manufactured and assembled same as Linconl Towncar Chassis only replace standard springs with part numbers C-0002 and C-0003. Replace standard tires with part number C-0007. Replace standard wheels with part numbers C-0006				
Front Springs	C-0002	Eibach					
Rear Springs	C-0003	Eibach					
Front Suspension	C-0004	Ford OEM					
Rear Suspension	C-0005	Ford OEM					
Wheels	C-0006	Center Line					
Tires	C-0007	Goodyear					
Interior							
Driver Seat	I-0001	Jaguar OEM	Obtain from Vendor		1. Carpeting 2. Dash 3. Seats and Options	Clips & Bolts	Standard Lincoln tolerances for Interiors
Passenger Seat	I-0002	Jaguar OEM					
Split Rear Bench	I-0003	Jaguar OEM					
Radio	I-0004	Alpine					
Nav System/DVD	I-0005	Alpine					
Speakers	I-0006	Alpine					
Mini Screens	I-0007	ProScan					
Wood Trim	I-0008	Jaguar OEM					
Computer	I-0009	Dell					

Conclusion

The educational design process presented covers several capstone design fundamental topics. These topics include: the engineering design process, teamwork, brainstorming, conceptual designs, proposal writing, project planning, project management, ethics, product attributes, design criteria, engineering targets, physical simulation, virtual simulation, analysis techniques, design synthesis, alternative designs, bill of materials, bill of process, manufacturability, product variations, product quality, design reports and presentations.

Besides developing students' engineering and communication skills the presented design process fosters creativity, the main educational objective in capstone design, and logical product realization engineering and project management skills. From the level of creativity and quality of the resulting capstone design projects and students' feed back it seems that the process is successful in meeting and exceeding its educational objectives. The process provides a road map for achieving the desired product attributes while allowing students to think freely and creatively out of the box. It also provided design and project management experience, in teamwork setting, based on real life industrial practices of leading corporations.

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Biographical Information

MOHAMED El-SAYED, Ph. D. is a professor of Mechanical Engineering at Kettering University and has been teaching at the undergraduate and graduate level for over 25 years. He teaches Machine Design, Automotive Design, Design Optimization, Mechanics, and Nonlinear Finite Element analysis. He is a consultant for several engineering corporations and has over fifty research papers on multidisciplinary Design optimization.