Teaching for Success; Molding Course Syllabi to Support Student Capstone Design Work.

Abstract

This paper details the curriculum changes made within both the aeronautical and automotive sub-disciplines of the United States Military Academy's (USMA) Mechanical Engineering (ME) program to support student senior design projects. Based on instructor/advisor observations, both sub-disciplines realized a need to better support student design by front-loading crucial design concepts and methodologies in their respective courses. A review of the USMA mechanical engineering curriculum is addressed illustrating the need for these syllabi changes. The aeronautical and automotive syllabi changes implemented and their impact on the performance of the student design teams is analyzed through student design team feedback survey results. Overall, the implemented course changes more effectively prepared students to execute the detailed analysis necessary for a successful design.

Background

Like engineering students at most universities, senior students in the USMA Mechanical Engineering program complete a capstone design as the culminating experience in engineering education. In the case of the aerospace and automotive sub-disciplines, these capstone projects are normally intercollegiate design competitions, and therefore very discipline specific. Consequently, the students are highly dependant on the senior level course in their sub-discipline to provide them with the technical knowledge necessary to successfully design a vehicle. Until recently these courses were geared toward general education within the sub-discipline and did not address the specific needs of the design teams (in essence, their customers). However, based on advisor observations and student feedback, these elective courses modified their course syllabi to better prepare students for the design process. This paper details the changes made to those courses and the impact on the capstone design projects.

The ME curriculum at USMA consists of six possible sub-disciplines, including aerospace and automotive engineering. Each sub-discipline consists of the core ME program and two technical electives in the specific area – the first in the second semester of junior year, and the second in first semester of senior year as shown below. Aerospace engineering students take *ME387: Introduction to Aerodynamics*, and *ME481: Aircraft Performance and Static Stability*. Students in the automotive track take *ME491: Mechanical Power Plants*, and *ME492: Mechanical Powertrains and Vehicle Dynamics*.

Class of 2009
Aeronautical Systems Sub-Discipline

07-2 (Spring 07)	08-1 (Fall 08)	08-2 (Spring 08)	09-1 (Fall 08)	09-2 (Spring 09)
CE300 Statics/Strngths (3.0)	CE364 Mech of Mat (3.5)	EE301 Circuits (3.5)	HI301 Mil Art (3.0)	HI302 Mil Art (3.0)
LX20_ Foreign Lang (3.5)	MA206 Prob & Stats (3.0)	EN302 English (3.0)	ME380 Eng Materials (3.5)	LW403 Law (3.5)
ME370 CAD (3.0)	ME306 Dynamics (3.0)	MA364 Engr Math (3.0)	ME404 ME Dsn (3.0)	ME400 ME Seminar (1.0)
PH204 Physics (3.5)	ME311 Thermal-Fluid Sys I (3.5)	ME312 Thermal-Fluid Sys II (3.5)	ME481 Acft Perf (3.0)	ME480 Heat Transfer (3.5)
PY201 Philosophy (3.0)	PL300 Leadership (3.0)	ME387 Intro to Appl Aero (3.0)	XE472 Controls (3.0)	ME496 Capstone Dsn (3.5)
SS202 Pol Sci (3.5)	SS307 Intl Relations (3.5)	ME403 Manuf/Mach Dsn (3.0)		**Tech Elect** **(3.0)**

Class of 2009
Automotive Systems Sub-Discipline

07-2 (Spring 07)	08-1 (Fall 08)	08-2 (Spring 08)	09-1 (Fall 08)	09-2 (Spring 09)
CE300 Statics/Strngths (3.0)	CE364 Mech of Mat (3.5)	MA364 Engr Math (3.0)	EE301 Circuits (3.5)	HI302 Mil Art (3.0)
LX20_ Foreign Lang (3.5)	EN302 English (3.0)	ME312 Thermal-Fluid Sys II (3.5)	HI301 Mil Art (3.0)	LW403 Law (3.5)
MA206 Prob & Stats (3.0)	ME306 Dynamics (3.0)	ME380 Eng Materials (3.5)	ME404 ME Dsn (3.0)	ME400 ME Seminar (1.0)
PH204 Physics (3.5)	ME311 Thermal-Fluid Sys I (3.5)	ME403 Manuf/Mach Dsn (3.0)	ME480 Heat Transfer (3.5)	ME496 Capstone Dsn (3.5)
PY201 Philosophy (3.0)	ME370 CAD (3.0)	ME491 Power Plants (3.0)	ME492 Power Trains (3.0)	XE472 Controls (3.0)
SS202 Pol Sci (3.5)	PL300 Leadership (3.0)	SS307 Intl Relations (3.5)		**Tech Elect** **(3.0)**

Figure 1: Aeronautical and Automotive Systems Subdisciplines

The design process is taught in *ME404: Mechanical Engineering Design*, which students take concurrently with their 2nd sub-discipline elective in their senior year. This course teaches the fundamental design methodology and is where the student design teams are formed. Partway through the semester, the students transition from general design topics into their design teams and begin working on their selected capstone projects. Each team is assigned an advisor from the specific subdiscpline (aero/auto), which generally are the ME492/ME481 instructors. The current model releases the students from ME404 to begin work on LSN 18 of a 40 lesson semester, which limits the time allotted to the design teams and can induce a tight timeline. For example, during term 08-1 capstone design teams did not begin working on their specific design until October 8th, 2007. The aeronautical capstone this academic year is the SAE Design, Build, Fly competition, which begins Apr 18, 2008. This leaves just over six months to design, fabricate, and test a remotely piloted airplane. Because of this, design teams must be fully prepared to complete the design of their specific project once released to their capstone advisor. Obviously, the current model requires the supporting technical elective to properly arm the students with the requisite technical knowledge so that they may begin the design process immediately.

Aeronautical Systems Capstone

In ME481, students learn a detailed airplane design methodology in a three lesson sequence. This sequence addresses the weight-ratio method of aircraft sizing, calculating critical performance parameters (i.e. thrust to weight, wing loading, etc.), and aircraft configuration. Prior to AY 06, these lessons were always taught at the end of the semester (Lessons 35-38) in preparation for a glider design that is part of the course curriculum. While this worked well in the context of the course flow, it required instructors to "pre-teach" the design lessons to design groups in order to prepare them for their capstone designs. This proved extremely inefficient for the instructor, particularly in large classes where there were 2-3 capstone groups.

During AY 06 the design block was moved to the very first block of instruction in ME481 to "front load" the information for the design teams as shown below in Figure 2.

Case Study	Lesson	Topic
Aerodynamics and Aircraft Design	1	Course Introduction
	2	Aerodynamics Review
	3	Airplane Design I: Weight Ratio Method
	4	Airplane Design II: Critical Performance Parameters
	5	Flight Lab I: Airspeed Calibration / Speed – Power Tests
	6	Airplane Design III: Configuration
	7	Drag Polar I
	8	Drag Polar II
	9	Evolution of Flight Briefs
Propulsion	10	Aircraft Propulsion I: An Introduction
	11	Aircraft Propulsion II: Propellers / Recip Engines
	12	Aircraft Propulsion III: Turbo – Jets, Fans, Props
	13	U.S.S Intrepid Trip Section
Unaccelerated Performance	14	The Equations of Motion and Steady Flight
	15	The Fundamental Parameters of Aircraft Performance
	16	Thrust / Power Required & Available
	17	Stall Speed & High-Lift Devices
	18	Climb Performance
	19	Gliding Flight, Ceilings, & Time-to-Climb
	20	Range & Endurance
	21	**Exam 1**
Accelerated Performance	22	Turning Performance, the Pull-Up, & the Pull-Down
	23	The V-n Diagram & Accelerated Rate of Climb
	24	Takeoff & Landing Performance
Static Stability	25	Introduction to Stability
	26	Flight Lab II – Neutral Point Determination
	27	Static Stability – Main Wing
	28	Static Stability – Vertical Tail
	29	The Neutral Point and Static Margin
	30	Elevator Control and Elevator Hinge Moment
	31	Stick-Fixed vs. Stick-Free Static Stability
	32	Lateral and Directional Static Stability
	33	**Exam 2**
Glider Design	34	Glider Design
	35	Flight Lab 1 Compensatory Time
	36	Flight Lab 2 Compensatory Time
	37	Glider Design Compensatory Time
	38	Glider Design Compensatory Time
	39	Glider Competition
	40	Course Review and Critique

Figure 2: ME481 Syllabus for Term 06-1

While this enabled the students to learn the design methodology up front, it was inefficient because of the advanced nature of the design topics. Because it was taught so early, students had not been exposed to some of the underlying concepts employed by the design methodologies. For example, one of the critical performance parameters used in airplane design, thrust to weight, is a function of takeoff distance. However, the students had not yet learned about that parameter, requiring the instructor to discuss the variables associated with takeoff distance. The advantage of this was that when the students learned about takeoff distance in depth later in the semester, they more easily grasped the material since they had already seen it. Overall, moving the design block had some 2nd order effects that had not been anticipated, most of which decreased the expected gain in efficiency.

Based on the results from AY06 it was determined that the design block in ME481 would remain toward the beginning of the semester for AY07, but not as early as in the previous iteration. This would allow more of the prerequisite topics to be taught to minimize the concepts in the design methodology the students were unfamiliar with. It was also during this AY that the engineering design course, ME404, changed it's syllabus such that design teams were not formed until later in the semester. As a result of this change, the design teams would not begin work on their capstone projects until mid Oct. Because the teams did not need the airplane design methodologies until that time, the design block was moved back to LSN 16, as seen in Figure 3. This allowed more of the prerequisite courses to be taught prior to that block, and the students were better able to grasp the concepts. While this version still required the instructor to briefly "pull forward" some of the material taught later in the course, it was much more efficient than the AY06 model with the design block at the very beginning.

Block	Lesson	Topic
Aerodynamics	1	Course Introduction
	2	Aerodynamics Review / Aircraft Configuration
	3	U.S.S Intrepid Trip Section
	4	Drag Polar I
	5	Flight Lab I: Airspeed Calibration / Speed – Power Tests
	6	Drag Polar II
Propulsion	7	Propulsion I: Introduction
	8	Propulsion II: Propellers / Recip Engines
	9	Propulsion III: Turbo – Jets, Fans, Props
Design	10	Airplane Design I: Weight Ratio Method
	11	Airplane Design II: Critical Performance Parameters
	12	Airplane Design III: Configuration
	13	**Exam 1**
Unaccelerated Performance	14	The Equations of Motion and Steady Flight
	15	The Fundamental Parameters of Aircraft Performance
	16	Thrust / Power Required & Available
	17	Stall Speed & High-Lift Devices
	18	Climb Performance
	19	Gliding Flight, Ceilings, & Time-to-Climb
	20	Range & Endurance
	21	**Exam 2**
Accelerated Performance	22	Turning Performance, the Pull-Up, & the Pull-Down
	23	The V-n Diagram & Accelerated Rate of Climb
	24	Takeoff & Landing Performance
Static Stability	25	Introduction to Stability
	26	Flight Lab II – Neutral Point Determination
	27	Static Stability – Main Wing
	28	Static Stability – Vertical Tail
	29	The Neutral Point and Static Margin
	30	Elevator Control and Elevator Hinge Moment
	31	Stick-Fixed vs. Stick-Free Static Stability
	32	Lateral and Directional Static Stability
	33	**Exam 3**
Glider Design	34	Glider Design
	35	Flight Lab 1 Compensatory Time
	36	Flight Lab 2 Compensatory Time
	37	Glider Competition (Gillis Field House)
	38	Glider Design Compensatory Time
	39	Glider Design Compensatory Time
	40	Course Review and Critique

Figure 3: ME481 Syllabus for Term 07-1

In addition to moving the design block forward in the ME481 syllabus, the instructor also incorporated an aircraft design into course homeworks. Specifically, students were given the requirements for a typical r/c airplane, and were required to make critical design calculations and decisions based on the established design methodology. Because the problem imbedded into several homework assignments, students completed the design process incrementally, which served to effectively reinforce the design methodology.

The results of the aforementioned changes were positive. In the year before the changes were made (AY 05) only two of the three aeronautics design teams produced flyable prototypes, and only 1 team successfully made it to the competition. In the two years following the changes, all seven of the teams were able to fly their designs, and four of these seven attended their respective competitions. However, two other teams could have attended their competitions but were unable due to conflicts with the FE exam.

Currently there are three aeronautical design teams for AY 08, all of which are just now beginning the construction phase. Consequently, it is too early to measure their success based on prototypes produced. Based on the advisor's observations the design team was properly prepared to begin the design process and the team has demonstrated proper design methodology during the design process.

Automotive Systems Capstone

The ME492 (Mechanical Powertrains and Vehicle Dynamics) course provides much of the basic knowledge required of mechanical engineering majors to participate in the Society of Automotive Engineers' BAJA SAE competition. In academic year 08 a new course director took over the course. This course director had served as a committee member for the academic year 07's Baja-SAE team. In AY 07 it was quickly apparent that the Baja-SAE team lacked some basic knowledge required to proper design of the vehicle. A review of the AY 07 ME492 syllabus revealed some of the underlying causes:

Lesson	Title/Topic
1	Intro to Vehicle Dynamics (Coord. Axis)
2	Acceleration Performance I
3	Acceleration Performance II
4	Braking Performance I
5	Braking Performance II
6	Road Loads I: Drag
7	Road Loads II: Aerodynamics
8	Road Loads III: Rolling and Grade Resistance
9	Performance Lab: CARSIM
10	Wheels and Tires
11	Clutches and Band Brakes
12	Exam I
13	Gears and Manual Transmissions
14	Hydrodynamic Torque Converters
15	Simple Planetary Gears
16	Automatic Transmissions I: Compound PGS
17	AT II: Powerflow
18	AT III: Controls and Component Modeling
19	Transmission Simulation Lab I: Clutches
20	Transmission Simulation Lab II: PGS
21	Drive Line
22	Differentials, Final Drives and Axels
23	Ride I: Suspensions
24	Exam II
25	Ride II: Excitation Sources
26	Ride III: Quarter Car Model
27	Ride IV: Half Car Model
28	Steering Systems
29	Steady State Cornering I: Bicycle Model
30	Steady State Cornering II: Suspension Effects
31	Lab: Steering Dynamics
32	Trip Section: Consumer Reports
33	EDP Working Session
34	Exam III
35	Ground Mobility I
36	Ground Mobility II
37	Lab: Terramechanics
38	Track and Suspension
39	Hybrid Powertrains
40	Industry Trends Presentation

Figure 4: AY 07 ME491 Syllabus

Figure 4 shows that in AY 07 the ME 492 students did not discuss crucial topics in vehicle design (Suspension, Ride, and Steering) until lessons 25-31 (late October to mid November). By this point in the design process, the BAJA SAE team needed to have their frame and critical subsystems designed. Despite a number of discussions with committee members regarding the intricacies of frame and steering considerations in vehicle design, the topics could not be adequately addressed without the baseline knowledge gained through course discussion. As a result, for the first time in the history of Baja SAE participation at USMA, the team did not travel to competition. A serious design flaw in the steering characteristics of the vehicle prevented safe operation of the prototype. Corrections to the design could not be made in time for the competition.

With similar yet independent observations of the course content-capstone timeline mismatch observed by his Aero colleagues, the new ME492 course director and Baja SAE advisor took a different approach to the redesign of the automotive curriculum. Rather than present a vehicle design block within the course, the course director opted to front-load all critical vehicle dynamics lessons in an effort to ensure students had adequate knowledge to reach critical design decisions earlier in the semester. In compensation, the manual and automatic transmission lessons (less critical to Baja SAE) were moved to later in the semester. The final AY 08 syllabus is shown in Figure 5:

Lesson	Title/Topic
1	Intro to Vehicle Dynamics (Coord. Axis)
2	Acceleration Performance I
3	Acceleration Performance II
4	Braking Performance I
5	Braking Performance II
6	Braking Performance Lab: Intro to CarSim
7	Road Loads I: Drag
8	Road Loads II: Aerodynamics
9	Road Loads III: Rolling and Grade Resistance
10	Exam I
11	**Ride I: Suspensions**
12	**Ride II: Excitation Sources**
13	**Ride III: Quarter Car Model**
14	**Ride IV: Half Car Model**
15	**Steering Systems**
16	**Steady State Cornering I: Bicycle Model**
17	Trip Section: NHRA Finals and Mack Truck Factory
18	**Steady State Cornering II: Suspension Effects**
19	**Lab: Steering Dynamics**
20	Exam II
21	Clutches and Band Brakes
22	Lab: Gears and Manual Transmissions
23	Hydrodynamic Torque Converters
24	Simple Planetary Gears
25	Automatic Transmissions I: Compound PGS
26	AT II: Powerflow
27	AT III: Controls and Component Modeling
28	Transmission Simulation Lab I: Clutches
29	Transmission Simulation Lab II: PGS
30	Drive Line
31	Differentials, Final Drives and Axles
32	Trip Section: Consumer Reports
33	Wheels and Tires
34	Exam III
35	Ground Mobility I
36	Ground Mobility II
37	Lab: Terramechanics
38	Track and Suspension
39	EDP Working Session
40	Industry Trends Presentation

Figure 5: AY 08 ME492 Syllabus

As a result of the course re-structuring, lessons in ride and cornering that the new course director deemed critical to the success of the Baja, moved forward (in bold in Figure 5). With this structure, the students completed all vehicle dynamics lessons just as they were beginning their preliminary design work starting lesson 18 as described previously. Although the team still struggled with time management and teamwork challenges endemic of many undergraduate design teams, the baseline knowledge to make informed design decisions was present as shown in student feedback.

In an effort to assess the effectiveness of the course re-structuring, the course director provided a capstone design applicability survey to the ME492 students. In this survey students were asked to list the three most helpful lessons from ME492 toward their capstone project and make a determination of the lesson timing (too early, just right, too late). In addition, students were furnished with a copy of Figure 5 and asked to assess the lesson's helpfulness on their capstone work on a scale from five to one (five was "very helpful" and one was "did not prepare me for my capstone at all"). Student feedback from those not involved in an automotive capstone design project were excluded from this analysis. In total, 16 student responses were included.

Based on the student feedback the top 10 most helpful lessons are listed below:

Table 1: Top 10 Most Important ME492 Lessons

Lesson	Topic	Most Important	Helpfulness	Moved Forward
11	Ride I: Suspension Systems	10	4.06	Y
5	Braking Performance II	6	3.94	N
4	Braking Performance I	5	3.94	N
13	Ride III: Quarter Car Model	4	3.44	Y
14	Ride IV: Half Car Model	4	3.5	Y
3	Acceleration Performance II	3	4.12	N
2	Acceleration Performance I	3	3.94	N
15	Steering System	3	3.94	Y
22	Gears and Manual Transmissions	3	3.81	N
7	Road Loads I: Drag	2	3.1975	N

When specifically asked about the utility of ME492 in the capstone process, the students responded favorably, giving it a 4.61 out of 5. The top 10 lesson topics were rank ordered based on the number of respondents listing the lesson as one of their top three most helpful lessons for their capstone design work. The helpfulness column of Table 1 shows the average response when students were asked to rate the helpfulness of all 40 lessons on a scale of 1 to 5. The results in Table 3 show that 4 of the top 10 lessons were moved forward in the AY 08 ME492 syllabus. Unfortunately, as a result of the re-structuring, the ninth most important lesson (Gears and Manual Transmissions) was moved back from lesson 13 in AY 07 to lesson 22 in AY 08. Based on this feedback, the ME492 course director has opted to keep the syllabus as presented in Table 2 in order to remain responsive to the needs of the automotive capstone students.

Conclusion

The capstone design is a critical component of the USMA Mechanical Engineering curriculum, and contributes immensely to the student's understanding of the design process. Two of the larger sub-disciplines of the ME major, aeronautical and automotive systems, serve as feeder courses for students in capstone projects. Consequently, the course directors of the respective courses have modified their syllabi to better prepare the student design teams (i.e. customers) to conduct the engineering analysis required during the design process. Specifically, topics critical to the design process were brought forward in the semester to ensure the teams had the tools necessary. This practice proved effective as demonstrated by student feedback during their capstone design work as well as observations of the ongoing group performance in the design and construction of the capstone projects.

Biographical Information

MAJ Brian J. Novoselich graduated from the United States Military Academy in 1996 with a Bachelor of Science degree in Mechanical Engineering. He earned a Master of Science degree in mechanical engineering from the University of Texas at Austin in 2006. He has served in various command and staff positions during his Army career and is currently the course director for the automotive sub-discipline courses at USMA. In addition he is the head faculty advisor for the Baja SAE design teams.

MAJ Justin Highley graduated from the United States Military Academy in 1995 with a Bachelor of Science degree in Mechanical Engineering. He earned a Master of Science degree in mechanical engineering from the Georgia Institute of Technology in 2004. He has served in various command and staff positions during his Army career and during his tenure at USMA has course directed the aeronautical subdiscipline courses. He is the current faculty advisor for the SAE Design Build Fly team.