

A Student-Developed Teaching Demo of an Automatic Transmission

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Abstract

The core curriculum at the United States Air Force Academy emphasizes the engineering disciplines. The capstone of the core curriculum is a unique engineering design course, Engr 410—Engineering Systems Design, all cadets take regardless of academic major. In this course, sections of approximately 16-18 senior cadets are randomly grouped resulting in a diverse mix of academic majors, abilities, etc. Each section responds, as a class, to a faculty prepared statement-of-work (SOW). The SOW specifies *requirements* for a system the cadets must design and build without mention of *how* to meet those requirements. Each section generally has its own project, i.e., there is not a course-wide SOW. Cadets in one particular section of Engr 410 were tasked to develop a teaching aid on the operation of an automatic transmission for a popular senior-level engineering course, MechEngr 490--Automotive Systems Analysis. The faculty provided the section of Engr 410 two fully assembled 42LE transmissions donated by Daimler Chrysler. The transmission is of course a major subsystem of the automobile and is a part of the MechEngr 490 syllabus. However, the instructors in the course were not satisfied with the depth of coverage of the automatic transmission in the past due to a lack of suitable teaching tools. That is, automotive textbooks, as complete as they are, and static displays together with lecture cannot easily or clearly describe the operation of the automatic transmission. The design of the Engr 410 teaching demo evolved through several iterations as the cadets learned the operation of the transmission themselves. Armed with their own recent learning experiences, they devised a three-part teaching demo: a static cutaway of one entire transmission, a working demo of the gear sets using hardware from the second donated transmission, and a computer simulation that animates the motion of the two planetary sets for each of the five transmission gears, reverse through fourth. This paper describes the demo designed and built by cadets of Engr 410 and discusses how it was implemented into the automotive systems course.

Introduction

The United States Air Force Academy (USAFA) offers an elective senior-level automotive systems course that approximately 100 cadets take each academic year. This course examines all major automotive subsystems from the engine and drive train to the suspension, steering, braking, and tires via an engineering approach. Despite the apparent comprehensive treatment of the entire automotive system, only a single one-hour class period was devoted to the automatic transmission (AT). We believe a more complete coverage of the AT beyond a cursory description of its major components and their functions is appropriate for an automotive engineering course.

Since working authentic automotive subsystems are a highly desirable complement to classroom discussions, engine, differential, and steering subsystem demos, for example, have been successfully implemented in the course and generally lead to a deeper understanding of a component's operation. Likewise, a more comprehensive treatment of the automatic transmission would be facilitated if such a working demo were similarly included in the course. In developing a teaching demo of the AT, we received significant assistance from cadets through another course, Engr 410—Engineering Systems Design. Engr 410 is the capstone course of the USAFA core curriculum where a small group of senior cadets design and build a system that satisfies a faculty written set of specifications. Having students develop a teaching demo for other students seemed an ideal approach to help enhance student learning of the automatic transmission subsystem of the automotive systems course syllabus.

This paper will present the development of the automatic transmission teaching demo starting with an explanation of why a demo was desired. Next, Engr 410 is discussed first in general terms and then specific to the AT teaching demo project. The product developed by the cadets of Engr 410 is then described. Finally, we will present the impact of the AT demo on the automotive course.

Why a Teaching Demo of an Automatic Transmission?

Prior to the Fall 2000 semester, the operation of the automatic transmission subsystem was presented during a single one-hour class period. We introduced the major components: torque converter, planetary gear sets, clutches and bands, and hydraulic computer, and their functions. We discussed the operation of the torque converter using an actual cutaway that shows its three components. The operation of a planetary gear set was described aided by a small plexiglass gear set. The gear set demonstrates the input-reaction-output function with different sun-carrier-ring combinations giving various gear ratios. We would then only briefly describe the functions and operation of the clutches and bands and valve body not adding significantly beyond what is in the course textbooks (1-3). Whereas each of the major components of the automatic transmission can be adequately described as individual parts, an explanation of the automatic transmission as a *dynamic system* is more challenging. We would attempt to present the system with the help of overhead transparencies of schematics such as that shown in Figure 1. These types of diagrams are certainly worthwhile additions to word descriptions and are typically included in automobile textbooks. However, the obvious disadvantage of such diagrams is they are static. For example, it is difficult for the novice to visualize how the clutches and bands are engaged to interact with the planetary sets resulting in the different transmission gears. To fully understand the automatic transmission as a system, moving parts are required. A way to show moving components was considered paramount to a more complete treatment of the automatic transmission.

In addition, a demo of the automatic transmission could be incorporated into the Machine Design course that Mechanical Engineering programs typically require. Experience with authentic gear train hardware should result in more student enthusiasm towards learning in that type of course as well.

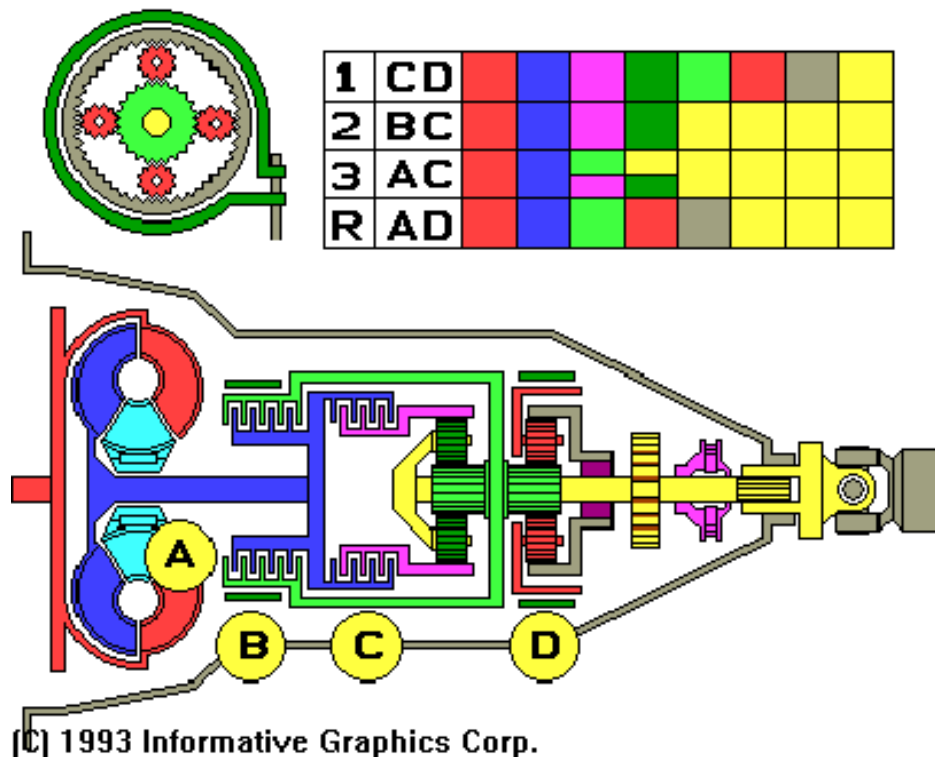


Figure 1. Schematic of Simpson Automatic Transmission Used in Mech490—Automotive Systems Analysis

Engineering 410 at the US Air Force Academy

The United States Air Force Academy's (USAFA) core curriculum is heavy in the engineering disciplines. The capstone of the core curriculum is a unique engineering design course, Engr 410—Engineering Systems Design administered by the Department of Astronautical Engineering. The instructors for the course are faculty members from the five engineering departments. In addition, senior members from any of the academic departments as well as from other USAFA agencies often serve as senior reviewing officers (SRO). This course is a graduation requirement regardless of a cadet's academic major. Through Engineering 410, the cadets gain valuable team problem solving experience and are also introduced to the Department of Defense systems acquisition process.

Individual sections of the course are comprised of approximately 16-18 senior cadets that have been randomly grouped resulting in a diverse mix of academic majors, abilities, etc. Each section responds, as a class, to a faculty prepared statement-of-work (SOW). The SOW specifies *requirements* for a system the cadets must design and build without mention of *how* to meet those requirements. It is not the instructor's role to suggest solutions to the SOW, but to help

guide the class to a solution that meets the customer needs as outlined in the SOW. Each section generally has its own project, i.e., there is not a course-wide SOW.

Encouraging the class to focus on the requirements of their SOW is an early challenge for the instructor. During the first week of the semester, each cadet in the class is required to briefly present his approach to the SOW. These presentations not only help the cadets gain a full understanding of the requirements, but also lead to brainstorming. In addition, specific questions about the requirements usually are raised. The most promising approaches might then be brought to the customer leading to more discussion and finally, a complete understanding of the desired product. Parallel to this ideation process, the cadets must choose a leader, the “program manager,” within the first two weeks of the semester and then start forming a class hierarchy, i.e. a “company,” they believe will help lead to successful project completion. Once the cadets choose their leader, the instructor no longer runs the class; the cadets decide how to best spend their class time.

Once the SOW requirements are fully understood, a skeleton class hierarchy is in place, and some approaches have been devised; the instructor and the in-house developed course textbook assist the class in meeting the next objectives. The company submits a proposal, a formal document that outlines their intentions on developing a design that will fulfill the requirements. Next, an engineering analysis package proves their approach is feasible. Successful completion of these latter requirements allows the class to focus on the first major design review. The first major review occurs about six weeks into the semester when the team presents a design that proves on paper how all of the SOW requirements will be met. The customer, SRO, and instructor must approve the design. Upon approval, permission to acquire materials, begin construction of subassemblies, and formulate test plans is granted. Efforts are now focused on specific tasks leading to a finished product that meets all SOW and customer requirements.

Engineering 410--The Automatic Transmission Project

During the Spring 2000 semester, cadets in one particular section of Engr 410 were tasked to develop a teaching aid for the AT, to be used in a popular senior-level engineering course, MechEngr 490—Automotive Systems Analysis. The faculty provided the section of Engr 410 two fully assembled 42LE transmissions that were donated by Chrysler¹. The statement of work (SOW) was brief and stated in part:

“...design, build, test, deliver and install a self-contained, *working cutaway* of an actual 42LE Chrysler automatic transmission. A personal computer graphical simulation of the transmission operation is considered an integral part of this requirement.”

Following the above general requirements, the SOW listed several additional specific requirements. Most important was a requirement that stated the product be a “*teaching demo* of the 42LE automatic transmission.” Other specific requirements were included on safety, size and portability of the demo, and documentation of its operation. One additional requirement

¹Thanks to Mr. Steve Horban of Daimler Chrysler for donating the transmissions to USAFA

involved meeting periodically with the customer, an instructor of MechEngr 490, in order to “better understand these requirements.” The aforementioned represented the entire SOW; the SOW stated requirements the product must satisfy without suggesting how a product might meet them.

The two phrases of the SOW shown in italics above, “working cutaway” and “teaching demo” were the two key requirements. The “working cutaway” requirement perhaps made the project seem more difficult than it really was. We did not have a realistic expectation the cadets could strictly meet this requirement. That is, we believed an operational AT that was cut open was too challenging, perhaps not even possible. However, since a static display of the 42LE AT was exactly *not* wanted, the SOW used vague wording to avoid biasing toward some specific solution. If the class could convince us, using technical arguments, that this ideal approach was not feasible, then we would back down from the working cutaway requirement. We stressed that we wanted a *teaching demo* that has moving parts and students must be able to see the parts move. To determine the feasibility of a working cutaway, members of the class had to learn how the 42LE AT worked.

Several cadets showed initiative from the beginning of the semester. Two cadets researched and then purchased a training manual on the 42LE AT (Ref 4) and began to study it. Another two began disassembling one of the transmissions. *The two cadets who initially began disassembling the transmission early in the semester, influenced by those who had studied the training manual, had the greatest impact on the eventual design of the demo.* These two cadets were the leaders in learning how the transmission worked and initially their efforts went mostly unnoticed. At first, their understanding was superficial but grew deeper as other members of the class eventually made demands on them. Consequently, they were asked to explain its operation to others and were therefore forced to consider how best to do that.

Meanwhile, many other members of the class including the program manager and his primary assistants concentrated on preparing for the first major review. However, of the major submissions that lead to the first review, the technical proposal and engineering analysis package lacked adequate specifics of their approach and were not satisfactory. That is, the class promised to deliver a product that met all of the SOW requirements but without any convincing detail on how they were going to do this. Furthermore, the engineering analysis package included minimal analysis! Well into the semester, it was clear to the instructor that most of the class, including those cadets in formal, company leadership positions, did not yet have even a rudimentary understanding of how a transmission works. Therefore, the class was not in a position to propose that a working cutaway was even feasible. In both formal written and informal oral feedback, the instructor continually asked for the missing specifics including an explanation of what would be visible to the students of MechEngr 490 if we accepted their approach. Since the company leadership was struggling to answer this question, we were skeptical the class would eventually deliver a product we could use in the automotive course.

During a practice presentation immediately prior to the first major review, the class finally began to come together as a team. The cadets were planning to present the same vaguely defined working cutaway design that was deemed unsatisfactory in the proposal and engineering analysis package. That is, the SOW requirements were ostensibly met but clearly enough study

had still not been done to know if their approach was feasible or even met the customer needs. At the completion of the dry run, comments were solicited from the rest of the class. One of the two cadets who had the most experience with actual transmission hardware obviously had not been consulted in preparing the proposal or the upcoming major design review. Referring to the operation of the AT that was presented, one commented: “that’s not the way *I* would explain it, *I* would...” and he proceeded to give an alternate approach. His “devil’s advocate” remark and the subsequent agreement from the second cadet who also knew a little on how the transmission worked, led to a chaotic, somewhat panicked, but ultimately productive class discussion on how to proceed.

The class eventually adopted the suggestion made by the cadet devil’s advocate and abandoned the operating cutaway approach with our approval. Suggestions were made at the design review that firmed the approach described in the next section. Now the cadets were finally focused on a product the faculty approved of. Progress was fairly smooth throughout the remainder of the semester with the exception of some late problems with the computer simulation.

Three cadets volunteered to work on the computer simulation subsystem of the teaching demo. All three were computer science majors and they enthusiastically proposed a three-dimensional, animated version of a schematic similar to that shown in Figure 1. After some research, the cadets proposed using AutoDesk’s Mechanical Desktop[®] (<http://www.autodesk.com>) and MSC Software’s Working Model 3D[®] (<http://www.mssoftware.com>) to prepare the animations of the five transmission gears. The animations would be activated via a graphical user interface developed using Microsoft Visual Basic. Their vision, although exciting, was perhaps a bit too ambitious. They spent a significant amount of time early in the semester becoming familiar with both of the CAD programs that none had any prior experience with. They then developed lifelike renderings of many of the transmission parts based solely on measurements taken directly from the hardware. However, since they neglected to request drawings of the gears from Chrysler—despite our suggestions—and did not know gear theory, they experienced significant difficulties in getting the gears to properly mesh in the Working Model simulations. After adjusting the gear geometries through a time-consuming trial and error process, they were able to finally get some limited animations. However, not only were the sun, planet, and ring gears difficult to see in their animations, their motions were not entirely correct.

For these reasons, most of the cadet-developed computer simulation was abandoned at the completion of Engr 410. However, the cadets proved the feasibility of their approach and indeed inspired the instructor to carry it forward after the semester ended. In retrospect, we should have more strongly encouraged getting accurate drawings of the gears from Chrysler. In addition, some knowledge of gear theory would have been helpful. As a result, the instructor in the course reworked the computer simulation using gear theory and accurate gear geometries.

Coincidentally, three of the cadets in the Engr 410 section had taken the automotive systems course the previous semester. Because of this, the faculty was initially optimistic that their automotive engineering expertise would help the section deliver a worthwhile product. Unfortunately, this was not the case. On the very first day of class in Engr 410, one of the cadets

publicly lamented that they had not spent much time on the automatic transmission in MechEngr 490 because it was so “hard.” As a result, many in the class were convinced at the outset that their project was the most difficult in the course and could not be done. The instructor had to “fight” this attitude throughout most of the semester. With limited success, we attempted to convince the class that the AT was difficult to understand in MechEngr 490 due in part to a lack of appropriate teaching aids, and hence their important tasking! The three cadets who had taken the automotive systems course the previous semester and presumably knew the most about its mechanics were reluctant to get directly involved with the transmission. That is, although their total overall contributions were fairly important to the success of the project, e.g. one of the three was the program manager, each preferred to work in other areas. Clearly all three did not have confidence in their knowledge of how an automatic transmission works. We believe the class could have benefited greatly if we were able to motivate these three cadets to extend their mechanical engineering expertise to the actual transmission. Curiously, whereas the mechanical engineering cadets were reluctant to extend their expertise to the AT, the computer science cadets working on the simulation enthusiastically embraced their challenge. A final Engr 410 comment: the two cadets who originally began disassembling the transmission and most influenced the project ironically were not engineering students.

A Description of the Teaching Demo

Despite the early challenges experienced in Engr 410, the cadets developed an effective teaching demo. The cadets and faculty agreed on a three-part demo: a portable static cutaway display, a working demo of the gear sets and input/output splines using actual hardware from the second 42LE AT, and a computer simulation that animates the operation of the planetary gear sets for each gear.



Figure 2. Portable Static Cutaway Display. Removable Working Demo of Gear/Spline Assembly is Shown at Left Mounted on Actual Input Shaft.

In the static cutaway of Figure 2, the entire transmission is displayed and is used to explain how the power is transferred from the engine and torque converter to the front transaxle. The outer housing has been cut in three places to provide a view inside. From the top, some of the gear sets are visible as well as the clutch/spline hardware. At the rear end, the cover has been cut to show the output from the gear sets to the chain that redirects the power towards the front of the car. The third cut in the housing shows the differential and the differential and transaxle can be manually rotated to aid in their descriptions. Underneath, the valve body can be removed. Additionally, a hand crank rotates the transmission to reveal the underside and the AT can be locked in an upside down position.

Using parts from the second transmission, the gears and clutch/spline mechanisms are described via the assembly of Figure 3. Also shown mounted on its input shaft at the left end of the static cutaway of Figure 2, the assembly is comprised of the input and reaction splines and planetary sets. The assembly is removed and a student or the instructor can demonstrate the gears separate from the static cutaway. Figure 3 also shows a close up of this assembly both assembled and disassembled into its six spline and gear parts.

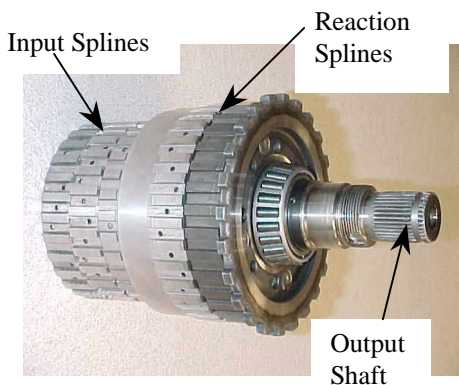


Figure 3. Working Demo of Planetary Sets and Input/Reaction Splines. Working Demo is Disassembled into Six Pieces at Right.

The assembly of Figure 3 shows the five splines for the 42LE transmission. The three on the left are the input splines, the two on the right are the reaction splines. During operation, one of the input splines links the shaft from the torque converter via a clutch to the input gear of one of the planetary gear sets. One of the two reaction splines is held by a clutch mechanism. (For a complete technical description of the 42LE operation, see reference 5.) Rotating by hand one of the three input splines and holding one of the two reaction splines, the five gears can each be *demonstrated*. For example, the instructor rotates the reverse spline, the third input spline that is rigidly connected to the front sun gear and simultaneously holds the second reaction spline that is rigidly connected to the front carrier. The output shaft, rigidly connected to the rear carrier/front ring, will then rotate in reverse. As this paragraph illustrates, it is difficult to adequately describe the AT gear operation without using the hardware! First, second, and overdrive are easily demonstrated in a similar manner. Gear ratios can be explained and demonstrated using this

assembly. The gear ratios can be calculated exactly based on gear tooth count in addition to approximated by rotating the assembly. The entire assembly rotates as a rigid body in third gear and is best demonstrated with the assembly mounted on the input shaft on the static cutaway. Although the five gears are easily demonstrated using this part of the teaching demo, one cannot see the two moving planetary gear sets within the assembly. The computer simulation addresses this.

Figure 4 shows a CAD representation of the gear/spline assembly of Figure 3. The CAD representation is shown within a graphical user interface (GUI) that was developed using Visual Basic. The user activates an animation by selecting one of the buttons at the right of the GUI. For example, the “Explode” button will run an animation showing the gear/spline assembly of Figure 3 being disassembled. The animated disassembly reveals where the two planetary gear sets are hidden within the assembly, see Figure 5 where four jpeg images give intermediate frames of the animation.

The cadets developed most of the images seen in Figures 4 and 5 through careful measurements of the actual parts. The instructor developed the planetary gear sets seen in the final image of Figure 5 using drawings donated by Chrysler after the Engr 410 semester had ended. The two sets of sun, planet, and ring gears are accurate renderings except for in the actual transmission, they are all helical versus the spur gears seen in Figure 5. All renderings were developed in Mechanical Desktop and then imported into Working Model 3D for the animations. The entire computer simulation is comprised of six animations in the form of avi files (5-7MB each) and an executable that displays the GUI and activates the avi files.

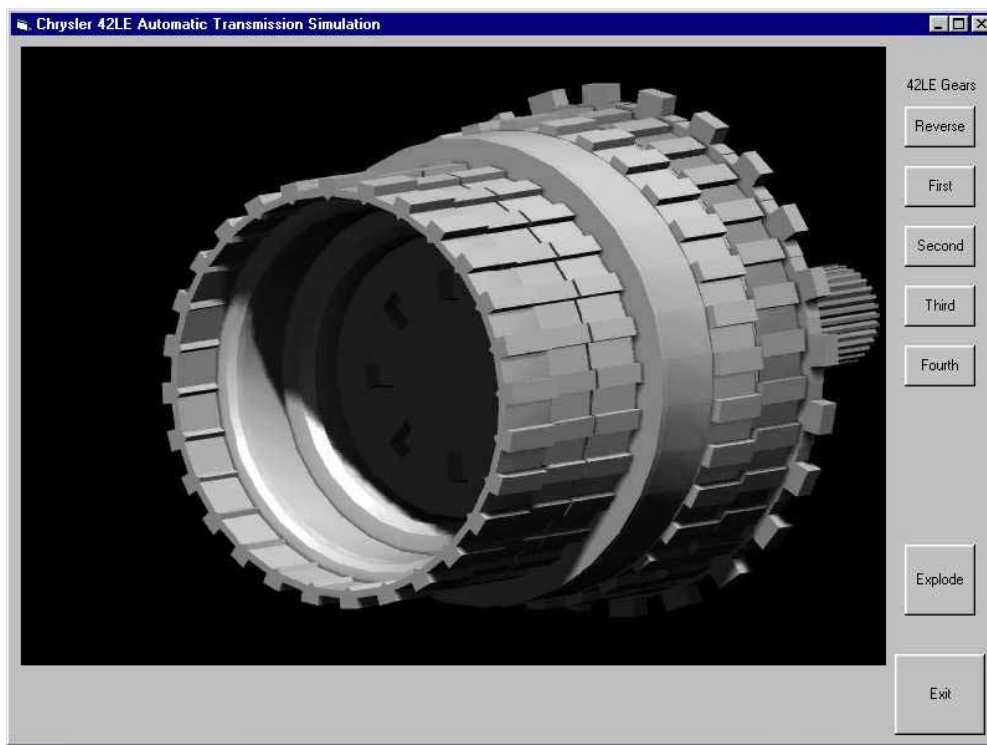


Figure 4. CAD Representation of Planetary Gear Sets and Splines Shown Within Graphical User Interface.

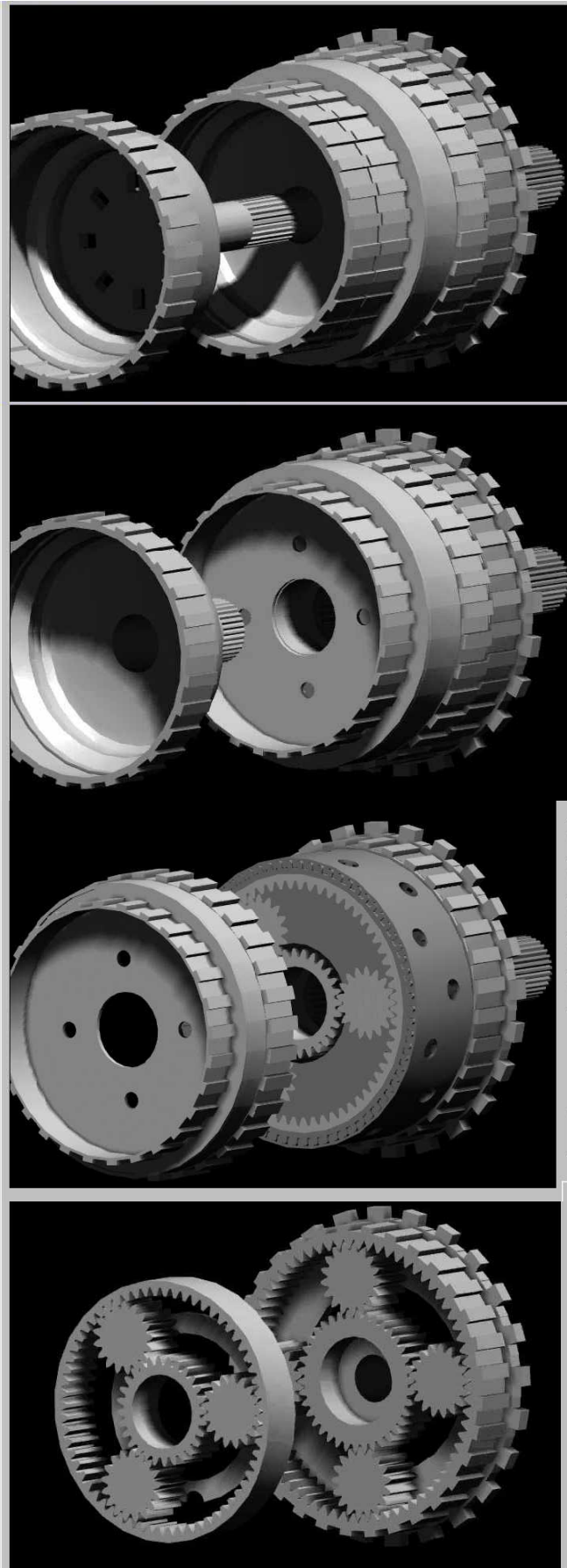


Figure 5. Exploding Animation of Gear/Spline Assembly Showing Planetary Set Location.

The final frame of Figure 5 is the view of the five transmission gears seen when any of the other animations are activated. For example, Figure 6 shows the “Reverse” animation. In the gear animations, the gears are colored to easily distinguish which planetary gear set component is the input, reaction, or output. For reverse, the input is the front sun gear and it is colored yellow. The reaction is the front carrier/rear ring and it is colored red. The output for all of the gears is the rear carrier/front ring and it is always colored green.

Note: If you are interested in downloading the computer simulation files, please email the first author at scott.dennis@usafa.af.mil.

Impact on MechEngr 490—Automotive Systems Analysis

With the addition of the AT demo, coverage of the automatic transmission has been doubled, to approximately 2½ hours. First, we introduce the major components of the AT and overview their operation as was done previously. Starting with the static cutaway demo, we can now physically point to each major portion of the transmission. Transfer of power is easily described using the cutaway. Furthermore, the students can see the physical location of the gears and how they integrate with the clutch packs and splines. The operation of the splines and gears are then demonstrated using the “dynamic” demo of Figure 3 in concert with the computer simulation. In addition to previously covered topics, we can now address actual gear ratio calculations through the transmission. We are also able to more thoroughly cover other items in the transmission, as the students can understand the system integration issues involved. For example, before the AT demo it was difficult to illustrate why clutch packs are sometimes used instead of clutch bands. With the combination of the three-part demo, a student can clearly see that the entire planetary housing must rotate in third gear, making bands unsuitable. Additional reading assignments have been developed on kinematics and gear ratio calculations for the 42LE, drawing on prerequisite course material. The kinematics and gear ratios are now easier understood using the three-part demo.

Assessment of the cadet’s retention of the AT subsystem has also been expanded in the course. Prior to the AT demo, the operation of the automatic transmission was assessed at a high level only using several multiple choice questions that might account for about 5% of a mid-term exam. Now, there are more detailed multiple choice and short answer questions on the AT testing a greater depth of knowledge and understanding. Also, we have required that the students calculate gear ratios on the exam. To do so, they must fully understand the operation of the planetary gear sets. The automatic transmission assessment now totals approximately 20% of a mid-term exam.

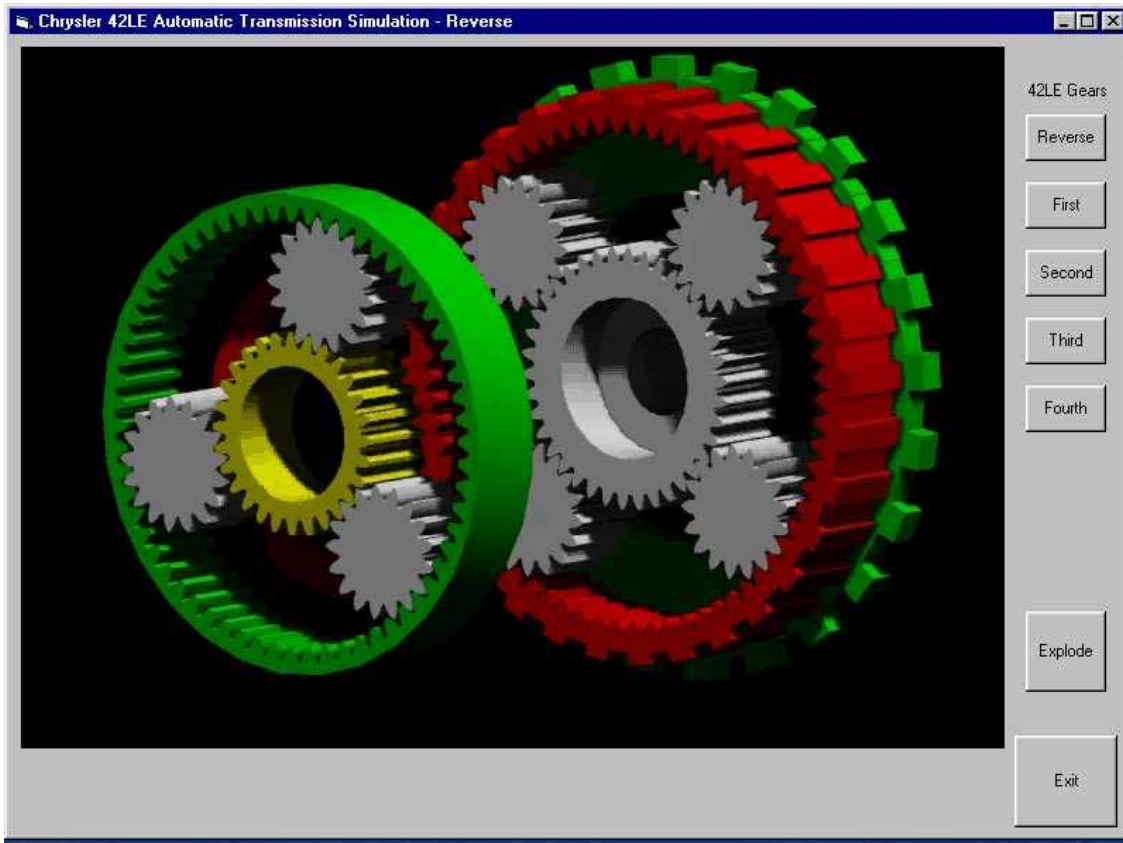


Figure 6. Computer Simulation of Reverse Gear.

Conclusions

Senior cadets from a core course were tasked to develop a teaching demo of an automatic transmission for an elective engineering course. We found that motivated cadets can learn the operation of a complex system like the automobile automatic transmission with minimal instructor intervention. Having just learned its operation themselves, the students were in a unique position to suggest teaching aids. Through faculty/cadet synergism, we have designed and built a powerful teaching demo of the AT. The teaching demo developed by students has helped fill a gap in the automotive systems course and provided a springboard for more in-depth engineering coverage of the AT.

A demo of the AT similar to that discussed in this paper could easily be developed by design or independent study students at other schools. The planetary gear set is typically studied in a Machine Design course and an AT demo would certainly aid in its understanding. Seeing actual hardware and its application adds an additional motivational element to the classroom and a further stimulus for thought and discussion.

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