43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit
8 - 11 July 2007, Cincinnati, OH

AIAA 2007-5150

An Advanced Solid Rocket Propulsion Class

Robert A. Frederick, Jr.,[1]
University of Alabama in Huntsville Propulsion Research Center, Huntsville, Alabama, 35899

Robert L. Geisler[††]
Geisler Enterprises, Tehachapi CA

and

Denis Creech[2]
University of Alabama in Huntsville Propulsion Research Center, Huntsville, Alabama, 35899

This paper describes the development and presentation of an Advanced Solid Rocket Propulsion Course at the University of Alabama in Huntsville. The course meets a critical NASA need to train a new cadre of Solid Rocket Scientists and Engineers to build the future generation of Orion manned space exploration vehicles launched by the new Ares booster. The course included 14 seasoned industry experts from around the nation giving lectures in their technical areas of expertise. The course instructor provided a student project, quizzes, and homework to document and assesses student accomplishments. The material was deployed as graduate-level college class in Mechanical and Aerospace Engineering and as a professional development class to the propulsion community in the spring of 2007. Forty eight students from around the nation participated in the initial offering as in class or distance learning students.

I. Introduction

With the following announcement NASA embarked on the quest to replace the Space Shuttle and develop the next generation of manned space vehicles.

> *WASHINGTON, Aug. 31, 2006 — Lockheed Martin won a multibillion-dollar contract from NASA on Thursday to build the nation's next spaceship for human flight, a craft called Orion that is to replace the space shuttle and eventually carry astronauts to the moon and beyond. The Orion contract calls for Lockheed Martin to get $3.9 billion through 2013 for designing, developing, testing and evaluating the new craft and building two for initial flights into space.*[1]

NASA is targeting April 2009 to test the first stage of its Ares 1 rocket, a five-segment booster evolved from its four-segment solid rocket boosters previously used to launch space shuttles into orbit. An artist's concept of the new Ares I booster is shown in Figure 1 below. A major participant in the development of this new launch vehicle will be the NASA Marshall Space Flight Center (MSFC) in Huntsville, AL. They will be standing up a new group of solid rocket scientists and engineers to support a major effort on the solid rocket first stage of this booster and the solid rocket crew escape tower.

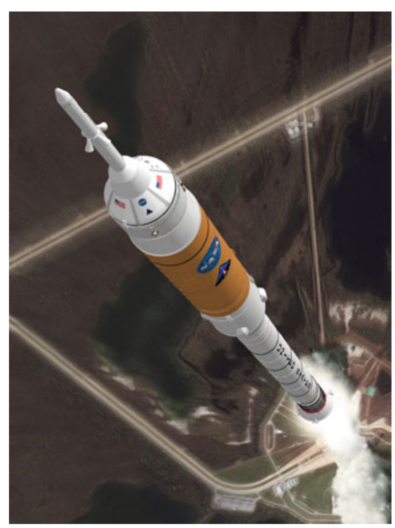


Figure 1. Ares I Crew Launch Vehicle

It is in this regard that the UAH Propulsion Research Center under the Direction of Dr. Clark W. Hawk Professor of Mechanical & Aerospace Engineering and Director of the UAH Propulsion Research was tasked by the nearby MSFC to help. He assigned Dr. Robert A. Frederick, Jr., Associate Professor of Mechanical and Aerospace Engineering and the Associate Director of the UAH Propulsion Research Center along with long-time

[1] Assistant Director, UAH Propulsion Research Center, 5000 Technology Drive, Associate Fellow AIAA.
[†] Senior Rocket Scientist, Geisler Enterprises
[2] Undergraduate Research Assistant, UAH Department of MAE, 5000 Technology Drive, Student Member AIAA.

national solid rocket consultant Mr. Robert L. Geisler to design the course. A curriculum of solid rocket technology courses to enhance and accelerate the training of their new and growing cadre of solid rocketeers was desired. This paper describes the initial quick-response effort by UAH, which started with the offering of an introductory set of lectures on solid rockets given in the spring semester of 2007.

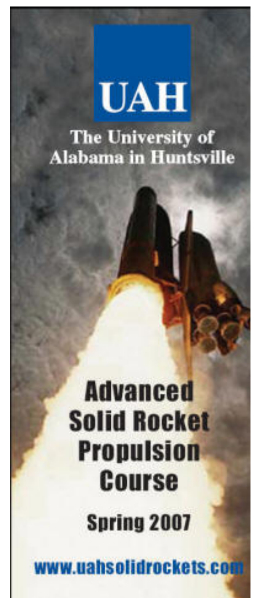
II. Approach

A. Course Development

It was decided to use the AIAA Solid Rocket Technical Committee (SRTC) outline of a Solid Rocket Textbook that that is in development. As a result we structured the course along the lines of solid rocket motor components. This was a first for propulsion textbooks in as much as they are generally written with academic orientation and often with emphasis on the author's field of academic endeavor such as fluid dynamics, heat transfer, combustion, etc. Our concept was to cover the 14 topics shown in Table 1 using highly experienced solid rocket design and development engineers skilled in each specialty area.

Table 1 – Outline of Advanced Solid Rocket Propulsion Course

Session/Topic	Presenter	Affiliation
1. Solid Rocket Motor Overview	Bob Geisler	Consultant
2. Solid Rocket Motor Design	Dan Meyer	Aerojet
3. Ballistic Modeling & Rb Analysis	Sam Schlueter	Aerojet
4. Propellant Fundamentals	Carol Campbell	ATK
5. Combustion & Two-Phase Flow	Jim Kliegel	Consultant
6: Propellant Grain Design	McKay Anderson	Consultant
7: Motor Case Design	Hugh Reynolds	Consultant
8. Thermal Protection & Insulation	Joe Koo	University of Texas
9. Nozzle Design	Russ Ellis	Consultant
10: Igniter Design	Rob Black	Aerojet
11: Motor Manufacturing	Dave McGrath	ATK Launch Sys.
12: Motor Demo & Performance	Paul Willoughby	Consultant
13: System Engineering &Trades	Ed Casillas	Aerojet
14: Motor Failure	Allan McDonald	Consultant
15: Project Presentations	Robert Frederick	UAH



We proposed the new Advanced Solid Rocket Propulsion Class for the spring of 2007. The course was offered course in two forms with two delivery methods:

Advanced Solid Rocket Propulsion, MAE 695, Graduate Engineering Class, 3 hours
- Traditional Classroom Setting at UAH
- Asynchronous Distance Learning through UAH

Advanced Solid Rocket Propulsion, UAH Professional Development, Continuing Education Credits
- Classroom Format
- eLearning format.

The MAE 695 course was positioned for students who are pursuing advanced degrees in science and engineering to take the course as part of an advanced degree program. The classroom setting was the home for all the presentations. The lectures were filmed with the in class students and the material deployed via CD ROM and the web to registered distance learning students. The material were judged to also be beneficial to practicing engineers and scientist who my need professional development. The same lecture materials were deployed thought the UAH Professional Development programs for continuing education units. Students could register for a section in which they attended class or an eLearning section in which they received CD ROM materials. This was a first-time collaboration of the Professional Development Department with and Academic course of this nature. Appropriate assessment and project materials consistent with the requirements of each forum were designed and used.

The graduate students were assessed with traditional items. An internet-based quiz was given on the content of each lecture. A homework assignment was given for each lecture. Students completed a project in which groups of two or three were each assigned to do more in depth research on one of the lecture presented. Students developed an extended bibliography on the subject lecture, retrieved open source references, and reviewed and evaluated the materials, developed an example exercise. They made an oral and written presentation of these materials which also included a summary of the important points of the lecture in their own words. The professional development students who participated remotely were assessed using a weekly, internet-based quiz on each lecture. They also were given some project reports from on undergraduate sounding rocket design class to evaluate using the principles that they had encountered in the lectures.

B. Public Access

Rocket propulsion has many technical areas that are governed by the Department of State under The International Traffic in Arms Regulations (ITAR). Since graduate courses are given to qualified university students, all the materials presented had to be prepared to meet these requirements. Prior to the beginning of the lectures we had the entire package of materials reviewed for unlimited public release by the Directorate for Freedom of Information and Security Review (DFOISR). This was done in a record time of just under two months and was crucial to being able to present the course as envisioned to the intended audience. We believe this represented a breakthrough of sorts since many people in our field have encountered difficulties walking the line between educating future scientists and engineers and protecting national security at the same time. We accomplished this by helping our lecturers to become aware of what is and is not releasable while they were preparing the documents and enlisting the NASA and Army representatives in Huntsville to assist in the reviews. This approach was appreciated by DFOSIR who responded with a timely and thorough review in a commendable manner. We believe our lessons learne
d here will help the entire community.

C. Course Participation

Many students from around the nation participated in the course. Table 2 presents a summary of the participants by the forum and deployment method.

Table 2 – Summary of Enrolment

15	Graduate Student - In Class
14	Graduate Students - Distance Learning
2	Professional Development Students - In Class
17	Professional Development Students - Distance Learning
48	Total Students

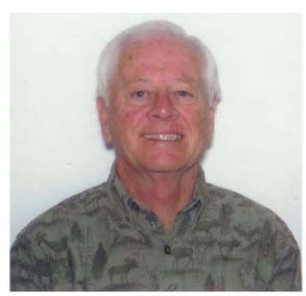
D. Student Feedback

As part of their project, students were asked to reflect on the course and give us an important "Lesson Learned" from the experience. .The following are excerpts form their comments:

- Motors and/or materials that are "in-spec-out-of-family" often lead to problems.
- Erosion is a result of the chemical reaction of graphite in the nozzle with water and CO_2 in the exhaust, not from particle abrasion
- Solid rocketry is a multifaceted discipline that requires coordination between various engineering specialties
- It is important to choose the correct beginning and ending points of a motor firing in order to accurately calculate the burn rate
- A propellant with n<1will self correct itself so that the motor will reach a stable operating point.
- The goal of a propellant designer is to create a propellant with the most energy and the least hazards. Hazard compliance is becoming increasingly important.
- Insensitive Munitions (IM) and Hazard Classification (HC) are not one and the same. Insensitive Munitions relates to field safety and Hazard Classification affects storage and transportation
- Limited market for rockets is increasingly forcing engineers to use less than optimum materials as suppliers drop product lines.
- Learned the tradeoffs of utilizing a un-submerged nozzle verses a submerged nozzle.
- The raw material procurement process, including the quality control and characterization of ingredients is critical to assure minimal voids, uniformity of burning rate, and equal thrust for parallel motor applications, i.e. the space shuttle
- There are major environmental considerations for solid rocket motor manufacture and test.
- The most important lesson that I took from this session was that of safety. This session was on motor performance and testing and it really emphasized safety. …. Since I work with solid propellants every day, I now have a better appreciation of what can happen if I don't take care of myself and those around me.
- Learned more about system trades and weighing the customer requirements against maximum system performance
- When doing failure mode analysis, it is often comforting to assume that it is extremely unlikely for a particular chain of events to occur, and therefore, a failure scenario can be logically dismissed. But, it can be the case especially with a relatively high flight rate that the unlikely can and does happen, often with disastrous consequences. These scenarios can't be simply ignored.
- Management needs to realize that they have surrounded themselves with the best people in the field and listen and respect what they have to say. Engineers need to stand their ground with accurate proof in hand. It may end your career, but it also may save lives.

We used this opportunity to attack a growing problem in the Aerospace community and particularly the Solid Rocket and Propulsion Industry to try to transfer the wealth of knowledge and experience from the rapidly disappearing and retired generation of scientists and engineers from the Space Race and "Cold War" era to the new generation. We were highly successful in this regard since the above list of lecturers represents 480 years of hands-on experience from the leaders of the solid rocket community who made everything happen from the Minuteman Silo Missiles to the large segmented satellite and shuttle boosters.

The following gives one of our best examples of the tremendous qualifications of the speakers describing Dr. McDonald, the wrap-up lecturer on Rocket Motor Failure:



Allan J. McDonald received a B.S. in Chemical Engineering from Montana State University in 1959 and an M.S. in Engineering Administration from the University of Utah in 1967. He worked in design engineering, project engineering, propellant development, and program management during his 42-year career at ATK Thiokol Propulsion, retiring in 2001. He worked on Minuteman, Trident, and Peacekeeper ICBM programs, Genie, HARM, and Standard Missile tactical systems, Malamute sounding rocket, PAM-DII space motor, and the Castor 4A, 4AXL, and Castor 120 space booster programs. He was also involved in several technology programs for controllable solid rockets, hybrid rockets, automobile air bag propellants, and environmental impacts of solid rocket motor exhaust. He was *the Director of the Space Shuttle Solid Rocket Motor Project at the time of the Challenger accident and led the redesign of the SRM as Vice President of Engineering for Space Operations in the return-to-flight program for the Space Shuttle. He received an Honorary Doctor of Engineering degree from Montana State University in 1986 and is a Fellow member and Distinguished Lecturer for AIAA. He has published over 80 technical papers and made presentations to numerous technical organizations and universities throughout the world. He has received numerous awards for his professional activities, does consulting for various aerospace companies and government agencies and is currently a member of the Board of Directors of Orbital Technologies Corporation in Madison, Wisconsin.*

We believe the distant learning materials will serve a valuable role in allowing additional participants as the word spreads about the excellence of the course. Many potential government and industry organizations have contacted us about the prospect of brining this course into their facility. They are particularly interested in the visual materials and transcripts of the lectures since there are no equivalent materials available in book form at this time.

III. Summary

This course set several precedents for solid rocket education. Traditional courses have been taught by one or two academic professors from a limited number of textbooks on the subject that focus on the physics as opposed to the engineering, components and materials from that enable the construction of solid rockets. This course was taught by 15 highly experienced active and retired solid rocket experts and each lecture focused on the real-world components they had designed, developed, and integrated into a large number of well-known rockets and missiles. The initial feedback from the students indicates that they were impressed by this approach and were very attentive to each of the two-hour lectures. Exams indicated that they learned many of the key points discussed in the lectures. Perhaps the most important point is that the students became excited about the technology and many expressed an interest in pursuing it in greater depth in future courses. We felt that the course was well balanced with respect to the total make-up of solid rocket motors and transitioned the high degree of compartmentalization seen in many groups in this field. The breadth of the view of the entire rocket represented by this course may help bring a more interdisciplinary approach and understanding to the subject.. The solid rocket community may well need a new generation of scientists and engineers who can take this broader view.

The ability to clear the course for unlimited public distribution was essential to accommodate the wide variety of students and to avoid the encumbrances otherwise involved in handling and distributing the course materials, particularly with respect to the distant learning participants. This approval from the government represents a breakthrough in today's intense sensitivity to such material. Our experience will undoubtedly help many other educators and textbook authors in the future. and provide an example for approaching the approval process.

The primary lesson learned is that there is a demand for courses of this type and style and that it may be useful to teach this complex course of "Rocket Science" with legacy engineers by starting with the broad view and develop a more specialized in-depth curriculum to follow.

We expect to polish the rough edges of this first endeavor and present the course again in the near future. We have also received many inquires about supplying the course and materials at many government and industrial sites involved in solid rocketry and expect to implement this process in the near future and on a continuing basis. We are also working with the AIAA Solid Rocket Technical Committee who supplied the carefully structured outline used for the course to achieve their objective of creating a new comprehensive and balanced solid rocket textbook for the propulsion community at large. It is important to note that this committee has broad international representation and these individuals will develop many of the chapters.

Acknowledgments

This work was sponsored in part by NASA Marshall Spaceflight Center though Jacobs EST (Dr. Karl Knight), in part by the University of Alabama in Huntsville Department of Mechanical and Aerospace Engineering, and in part by the UAH Propulsion Research Center.

The authors wish to gratefully acknowledge the contributions of the speakers who developed the details and made the presentations of this material. They had a challenging assignment to condense a lifetime of experience into a two-hour lecture. The performed with excellence and inspired all participants. In addition to the authors of this paper, the speakers included Dan Meyer, Aerojet; Sam Schlueter, Aerojet; Carol Campbell, ATK; Jim Kliegel, consultant; McKay Anderson, consultant; Hugh Reynolds, consultant; Joe Koo, University of Texas; Russ Ellis, consultant; Rob Black, Aerojet; Dave McGrath, ATK Launch Systems; Paul Willoughby, Consultant; Ed Casillas, Aerojet; and Allan McDonald, consultant.

The authors gratefully acknowledge M.M Langerman and W. King of the Department of Defense, Office of Security Review for their thorough and timely review of the materials for public release. We acknowledge the contributions of local NASA and Army professionals who assisted with an internal assessment of the materials for technical quality and public release issues.

Mr. Michael Rudolphi of NASA MSFC and Clark W. Hawk of the UAH Propulsion Research Center collaborated to math UAH's capabilities with NASA's educational needs. The authors acknowledge the assistance of Dr. Stephen L. Rogers (NASA MSFC) and Mr. Preston Jones (NASA MSFC) for taking the steps necessary to implement this vision. The authors acknowledge the AIAA Solid Rocket Technical Committee, especially Tom Moore, for their contributions to the outline of this course material. Aerojet and ATK management are acknowledged for financially supporting the contributions of the speakers associated with their company. David Mayo, UAH Graduate Research Assistant is acknowledged for assisting with deployment of the class. Dr. Phillip Farrington and the UAH ISE Distance Learning staff are acknowledged for arranging and performing the distance learning components of the class. Mrs. JoAnn Jones developed and administered the UAH Professional Development deployment of the course. Mrs. Dottie Luke, secretary of the ISE Distance Learning Department, is acknowledged for finding the phone number for DFOISR and thus saving the whole effort from certain failure. The Chemical Propulsion Information Agency is acknowledged for announcing the course to the propulsion community in its Bulletin so that many from around the country could participate in the first offering.

References

[1] New York Times, Business Section, Published September 1, 2006.