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The Reaction Research Society's Rocket Propulsion Courses

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ABSTRACT

An amateur experimental rocket group, the Reaction Research Society, has recently developed a "hands on" rocket propulsion class. While begun in the area of solid rocket propulsion, the training is now expanding to cover bipropellant liquid and hybrid rocket engines. Founded in 1943, the Society is the oldest continuously operating amateur experimental rocketry group in the United States. With members active in all areas of the propulsion sciences, it operates and maintains the largest privately owned rocket test facility, capable of both static and high altitude flight test, in the country. Utilizing these facilities and expertise for its continuing educational efforts, the Society offers an unparalleled rocket propulsion educational opportunity. A course text book was written to compliment the "every student builds their own motor" instruction style. A specific motor design was used as a method of transferring practical information in a reasonable amount of class and field time. The first day is classroom work covering theory, chemicals, materials, procedures, computer design software, and safety. The second day's instruction is held in the field mixing, casting, curing, and final processing propellant. The third day involves each student in setting up test equipment, calibrating instrumentation, and hot fire testing their motor under the guidance of a Society pyrotechnic operator.

INTRODUCTION

University level education in the field of rocket propulsion is usually centered around textbook course work and computer simulation. The difficulty of actually designing and fabricating rocket motor components, handling propellants, and setting up the required test facilities to conduct hot fire experimentation usually dissuades departments and students from attempting hardware oriented projects. As an added complexity, safety concerns, liability issues, and lack of staff personnel with actual experience in rocket testing operations make student level rocket testing all but impossible except for a very few. As a consequence, there has never really been an available satisfactory method of formally transferring practical level knowledge and experience to the interested student. As necessary as is the basic and theoretical textbook study, there is nothing more educational for students than to design, build, set up, calibrate, fuel, and hot fire test a rocket motor for themselves.

Within the past year, an amateur experimental rocket group called the Reaction Research Society has taken some great strides toward providing actual "hands on" rocket propulsion education. While begun in the specific area of solid rocket motor design, construction, and testing, the training being offered is now expanding to cover bipropellant liquid and hybrid rocket engines as well.

The Reaction Research Society was uniquely situated to organize and conduct this type of training. Founded in 1943, the Society is the oldest continuously operating amateur experimental rocketry group in the United States. With members active in all areas of the propulsion sciences, it operates and maintains the largest privately owned rocket test facility, capable of both static and high altitude flight test, in the country. The Society has, in recent years, greatly expanded its activities in the areas of high energy solid, hybrid, and liquid propellant propulsion. The establishment of formal propulsion classes was a natural extension of those activities. Among its membership, the Reaction Research Society has many experienced professional propulsion engineers and California state licensed First and Second class rocket pyrotechnic operators. Utilizing these facilities and expertise for its continuing educational efforts, the Society felt it could offer, to any interested student, the chance of safely working with real hardware, live propellants, and actual hot fire testing. By this means, it could provide an unparalleled educational opportunity and actively advance practical rocket propulsion education by making this type of propulsion information and practical knowledge more readily available.

DISCUSSION

Before proceeding further, some distinctions and definitions may be useful in explaining how and why the RRS undertook the development of a formal course in solid rocket motor design and fabrication. As stated previously, the Reaction Research Society persues what is known as Amateur Experimental Rocketry. Those who participate in this arena are involved with the design, fabrication, and test of rocket propulsion systems. Solid propellant, liquid bipropellant , liquid monopropellant , and hybrid engine systems up to 15,000 pounds of thrust (1,000,000 Newton-seconds) have been built by RRS members over the years. Individuals pursuing this type of rocketry calculate DeLaval nozzle throat areas, injector mass fluxes, feed system pressure drops, combustion efficiency, combustion stability, and specific impulse, to touch on just a few of the technical issues addressed. They also design and build a complex variety of stationary test equipment with which to study these engine systems including test stands, reinforced concrete bunkers, and blockhouses. Their efforts are directed at hard engineering, fabrication processes, structural and thermal analysis, and a host of other technical aspects of propulsion. Most of their activity centers around the static testing of these propulsion systems to determine functionality and combustion performance. Once in a while they even fly a rocket with one of these propulsion systems installed.

For the student interested in this field, it has always been difficult to round up the type of information that was practical and useful to the amateur hobyist or propulsion student. This problem has always left a void in the information base required by students. There has never been a method of formally transferring practical propulsion knowledge and experience to the interested student. In the past, instruction has always been through an informal sort of voluntary apprenticeship. More experienced members and licensed pyrotechnicians have provided guidance and oversight to less experienced members pursuing their individual projects. While this method has advantages and is still very useful, it is slow in transferring basic concepts and does not always efficiently cover all the required information.

Around 1993, two RRS members started a joint project to create a small composite propellant rocket motor that would serve as a relatively simple, standard composite flight vehicle, much as the existing " RRS Beta" has become the standard micrograin (zinc/sulfur) rocket. By standardizing a proven, single design, it would be easier for other interested members to learn about composite propellants and motors by duplicating it. The engine was designed to be 2.5 inches in diameter and produce 350 pound thrust for 2.5 seconds. The motor design and propellant processing procedures were established. Specialized equipment, such as propellant curing ovens, coring fixtures, and a static test stand, were designed and built. In addition, the infrastructure was set up to transport all of the required materials and equipment to the RRS's Mojave Test Area for mixing, casting, curing and hot fire testing. New facilities, such as the new Solid Propellant Processing Area (SPPA), were built at the test site to make instruction for classes of 10 to 15 students more comfortable. The project was extremely successful in developing ammonium perchlorate / HTPB propellant manufacturing techniques that produced excellent quality, high performance propellant grains in just a few hours without vacuum mixing. When these motors were configured for flight with a payload section, fins, and a nose cone, altitudes of over 18,000 feet were easily obtained. After the initial success of these motors during static and flight testing conducted in 1994, the idea was put forth to use this type of motor as a tool to formally teach a beginning course in composite propellants.

The decision was made by the RRS Executive Council to proceed with this first propulsion course using the newly developed composite motor. To provide the most comprehensive course possible, individuals within the RRS were selected as instructors for their specific experimental propulsion expertise. The individual instructors wrote and developed a course text book to compliment the planned "every student builds their own motor" instruction style. The information presented in this class would not be designed as an exhaustive study of composite propellant rocket propulsion. Rather, this specific motor design would be used as a method of transferring the maximum amount of useful information in the minimum amount of class and field time. By presenting some general information and then walking each student through the design and fabrication of this standard composite motor, the concepts involved could be clearly demonstrated.

The Society evaluated whether or not the class should be offered as just a written course book or even as a video tape. From many of the experiences of the instructors, it was decided that, without the direct supervision of instructors, it was too easy for students to misinterpret written, or even video instructions. In the absence of someone to ask a question of, this situation might lead a student into making a mistake that would potentially have dire consequencs. Although more involved, it was felt that the safest and most efficient way to teach the course was with knowledgable instructors face to face with the students. The students could then ask as many questions as they wished and would mix propellant and process the motors themselves, but under the experienced eyes of the instructors.

The course was set up to be a unique "hands on" three day event. The instructors would take each student through the basic design theory, general safety, propellant chemistry, propellant mixing, propellant loading, and set up for actual hot fire static testing. Students would spend the first day in classroom work covering theory, chemicals, materials, procedures, computer design software, and safety. The second day's instruction was to be held in the field at the Society's Mojave Test Area about 50 minutes driving time from the town of Lancaster, California where the classroom work would be conducted in a more comfortable conference room setting. Students would spend the second day mixing, casting, curing, and final processing the propellant grains required for their motor. Each student would be provided with all the necessary motor hardware, chemicals, and other materials to assemble and load a 350 pound thrust motor. All required propellant mixing/handling equipment and motor assembly tooling would be available for the use of the students. Individual instructors would be available throughout the day to instruct, answer questions, and provide assistance.

The third day of the course would involve each student in setting up test equipment, calibrating instrumentation, and hot fire testing their motor under the guidance of a Society pyrotechnic operator. All required instrumentation and test stand hardware would be available for the use of the student to conduct this testing. In addition to the knowledge and experience gained, the student would be able to take away from the course all instructional materials, handouts, a copy of the recorded test data, any pictures and videos the student cared to take, and the reusable motor hardware.

Although designed to thoroughly cover all required technical and safety information, this class was not designed just for "rocket scientists". While some basic understanding of solid rocket propulsion would be helpful, the course materials would be carefully prepared to be useful and instructive to a wide range of students from professional propulsion engineers to the beginning amateur experimentalist with little or no previous experience in rocketry.

Once the decision had been made to go ahead, a tremendous amount of work was accomplished quickly by the course teaching staff. To get a specific and knowledgeable critique of the course in its entirety, several experienced RRS members attended a preliminary class set up to refine and polish the course materials and procedures. In March of 1996, ten such experienced students / reviewers took the class. Several improvements were made to the written text and to the field operations required to manufacture the propellant grains and static test the motors. This first run also served to elevate the enthusiasm level of the participants considerably as the real value of the course was experienced.

The "students" began in the classroom with safety. The instruction covered general desert safety, personal protective equipment, some first aid, the necessity for detailed procedures, engineered safety features (such as remote processing), and RRS safety rules for propellant handling and live firing motors. The lectures proceeded into solid rocket design considerations including thrust level, burn duration, performance, weight, size, etc.. This was followed by hardware design topics such as motor case materials, nozzles, bulkheads, retainers, seals, insulators, igniters, and grain geometry. Motor design computer software for propellant grain design was also provided to each student and demonstrated to the class.

A large part of the classroom work was dedicated to propellant chemistry and detailed information about the "hows" and "whys" of many solid propellant ingredients including burn rate catalysts, opacifiers, additives, anti-oxidants, ammonium perchlorate crystal size effects, and aluminizing. Mixed propellant characteristics such as solids loading, viscosity, and curing were also covered. The propellant discussions were followed by igniter designs and characteristics. Materials, pressure effects, energy release, flame dispersion, duration, and required ignition energy were explained in some depth. The latter part of the classroom work was geared toward the activities that the students would undertake in the field the next day. Propellant mixing, casting, and curing processes were explained as were all of the materials and equipment that would be used to make the required propellant grains. Propellant grain finishing processes were also described and the equipment demonstrated in the classroom with inert materials.

The last topic covered was static testing. Final assembly of the motor and set up for testing was discussed along with information about instrumentation, data collection, and firing systems. By the end of the day, the students had been presented with a considerable body of technical information and instructors had explained every aspect of the field operations that the students would be experiencing over the next two days.

The following two days of field work went very well. Improvements were made in some motor and propellant processing procedures to help streamline motor fabrication. Other aspects of the work were verified and, on Sunday, fourteen motors were successfully static tested. All the motors demonstrated a specific impulse of around 235 seconds and all fourteen motors were within 1% of each other in total impulse. Representative data from one static test is shown in Figure 1.

With this initial success, the first official class was scheduled for April of 1996. The response to information about the course was so great that it was expanded from 10 to 15 students and we had to set up an overflow class for June.

Both the April and June classes were extremely successful. Some students came from local areas while others came from as far away as, Michigan, Minnesota, and Texas. Arriving with a wide variety of backgrounds from hardware salesman to computer specialist to solid rocket motor technicians, all of them were enthusiastic and helpful. The instructors learned a great deal from the students as they made suggestions and asked astute questions. The class was successful beyond all expectations. During the April class, sixteen motors were successfully hot fire tested in less than four hours on the last day. This was a new record for the Reaction Research Society.

CONCLUSIONS

The Reaction Research Society is one of the few remaining experimental rocket groups in the world. It is interested in doing everything it can to expand its capabilities, improve its technical expertise, and continue to provide the opportunities for anyone interested to conduct meaningful rocket propulsion experimentation. As this class continues, and others are developed, their administration will be managed by a close affiliate of the Reaction Research Society. This will allow the classes to continue and grow in close association with the RRS without transitioning the Society from an Amateur Experimental Rocketry group into a training establishment.

The Society believes that this is the only propulsion course of its type in the country today, providing not only expert theoretical instruction, but an opportunity for the student to get his or her hands dirty mixing propellants and hot fire testing motors. All of the students that have attended to date have come with the best of credentials - enthusiasm and a desire to learn. The interaction between students and instructors has been mutually beneficial and has expanded the experience base of the Society. Those Society members involved in the founding of these classes look forward to the long term benefits they may bring to the field of propulsion education.

The Reaction Research Society's solid propellant course has demonstrated that rocket propulsion education can be practically and safely extended from theory through hot fire testing. The course methodology and structure serve as models of how to integrate "hands on" rocket fabrication and testing with standard propulsion curriculum.

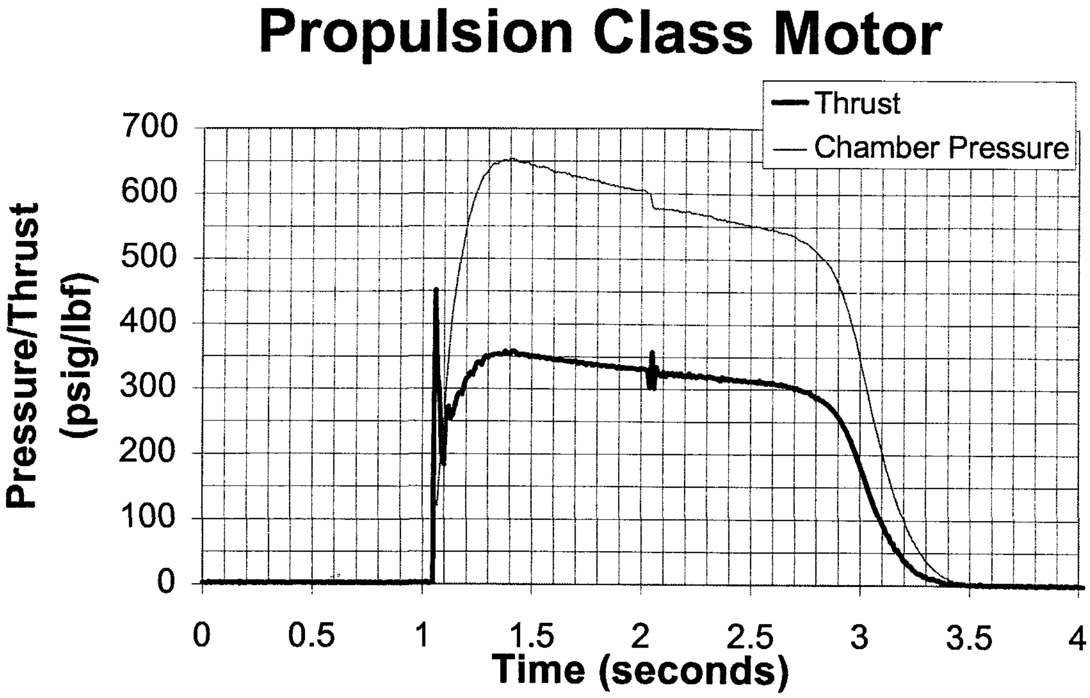
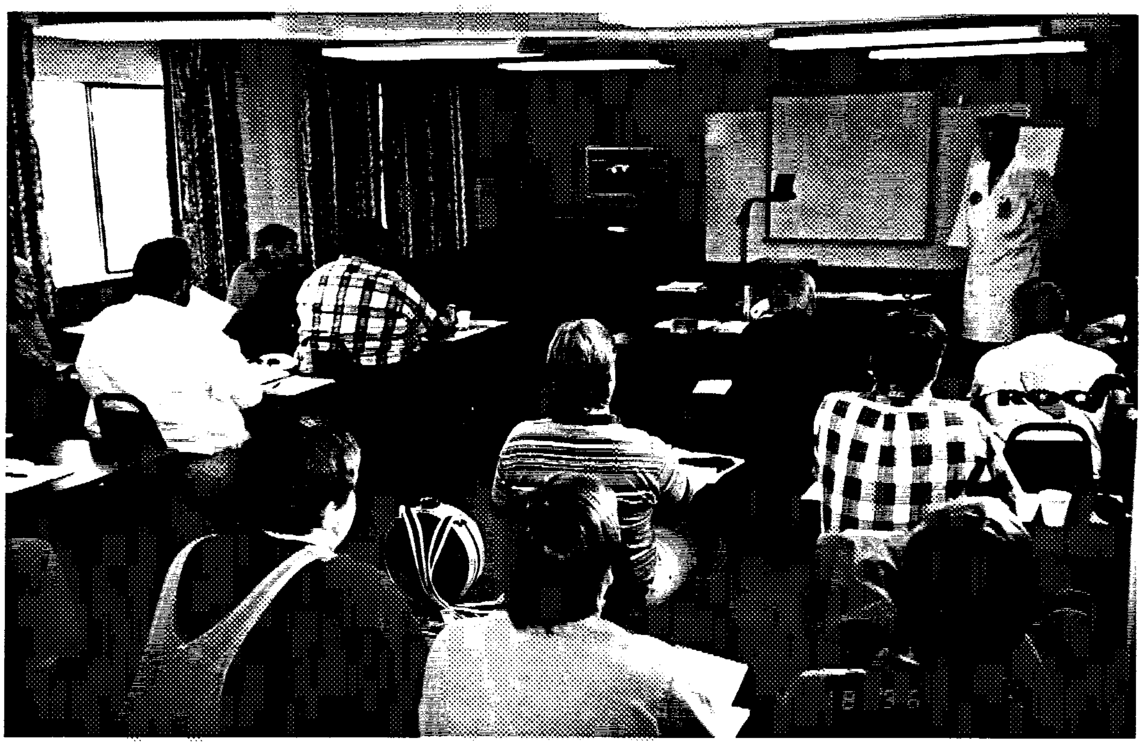
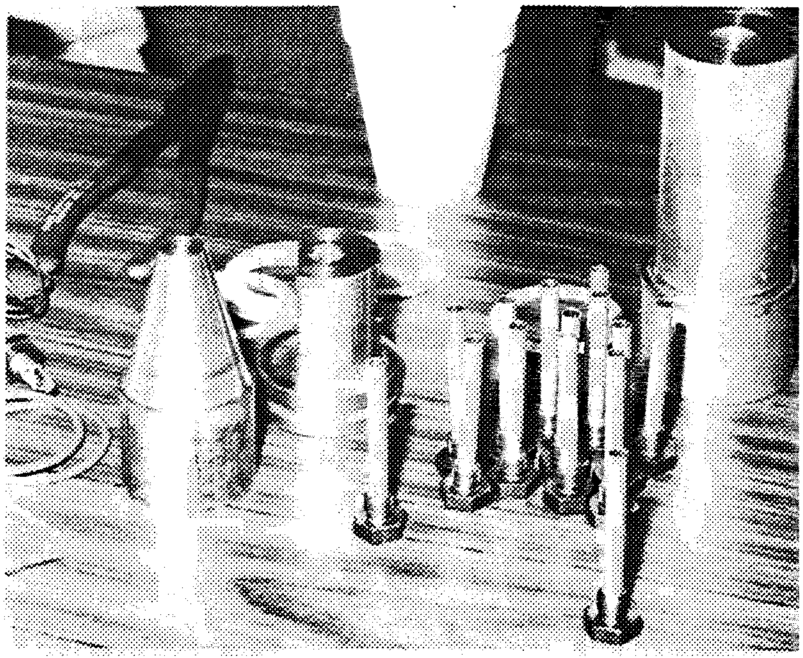


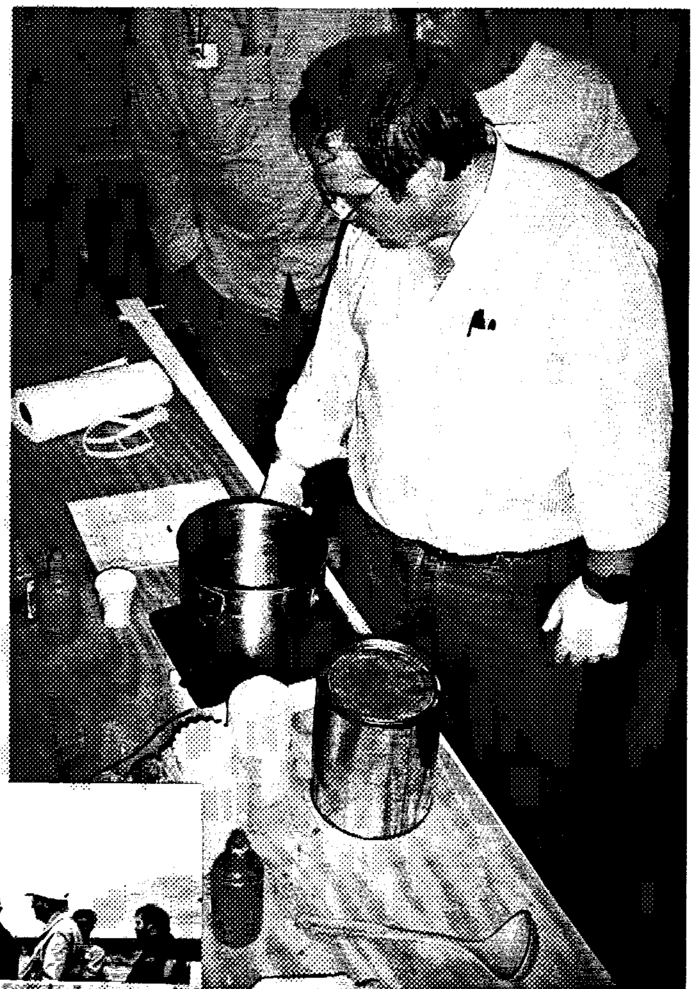
Figure 1. Typical chamber pressure and thrust data from a class motor. The spike in the chamber pressure trace at start is the igniter pressure and the jump in both traces is alumina flaking off the nozzle throat in mid burn.



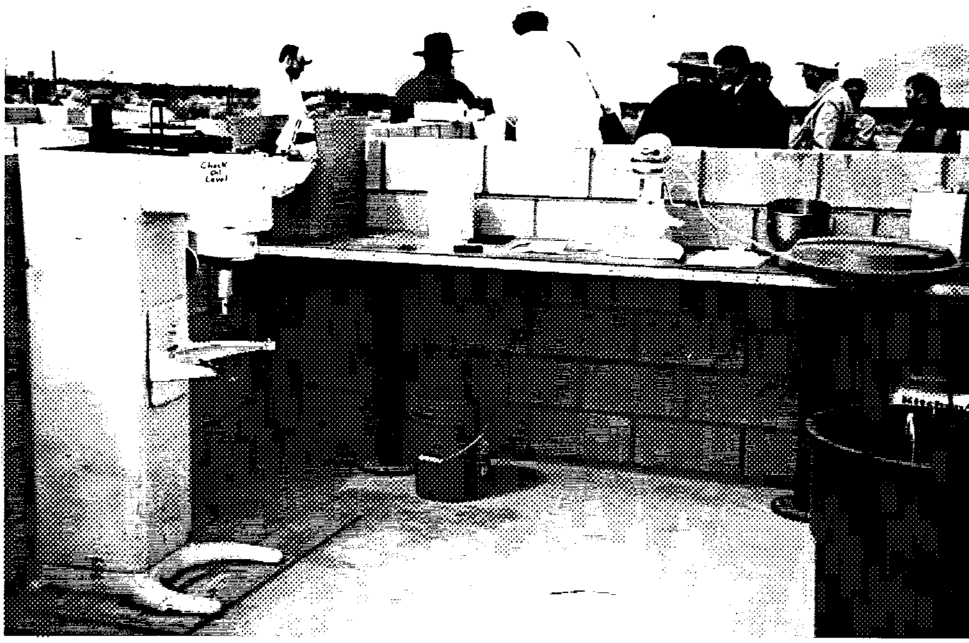
Not as exciting as the field work of the next two days, the information taught in the classroom is vital to understanding processes, principles, and safety



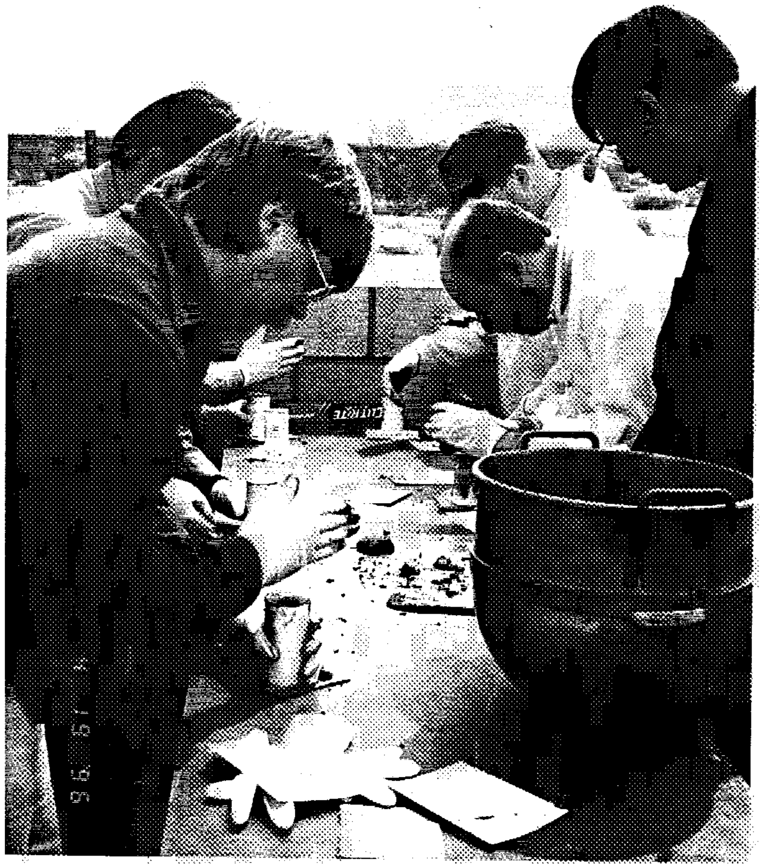
Fabrication hardware, inert igniters, tools, and fixtures are used in the classroom to explain every detail of motor design and assembly



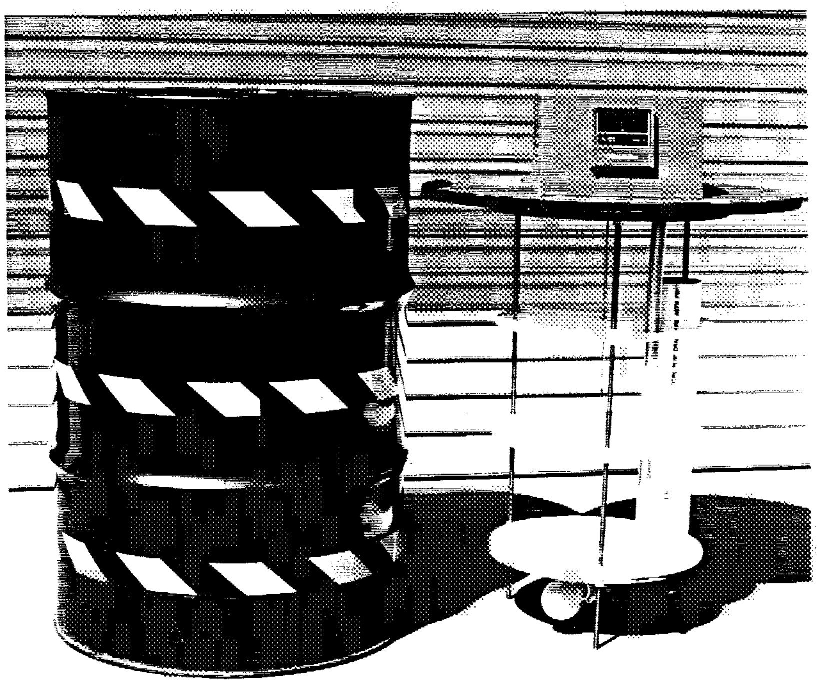
Out at the Society's Mojave Test Area, the field work begins with the careful weighing of propellant ingredients

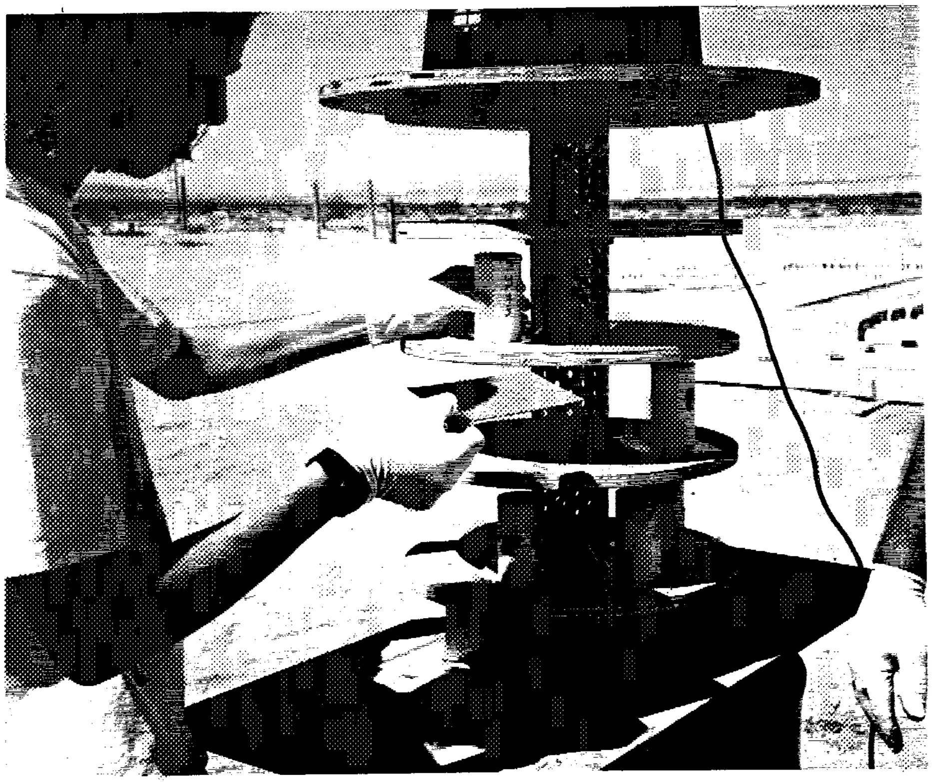


Equipment for propellant processing is set up in one of the bays of the new Solid Propellant Handling Area



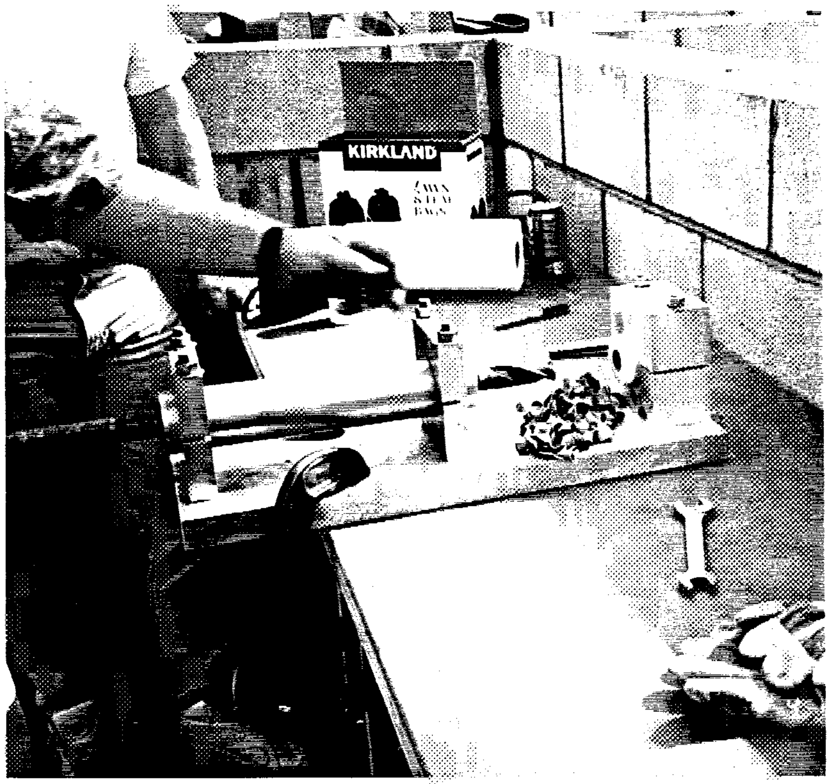
Top left; A large batch of composite propellant is mixed thoroughly. Top right; An instructor provides advice and an experienced eye as students pack the propellant into the grain liners. Below left; One grain is completed by a student and another is ready to be filled. Below right; The portable curing oven is part of the equipment built by the RRS for this course.





The filled cartridges are loaded by the students into the curing oven. The oven is closed and the propellant solidifies over the next few hours.

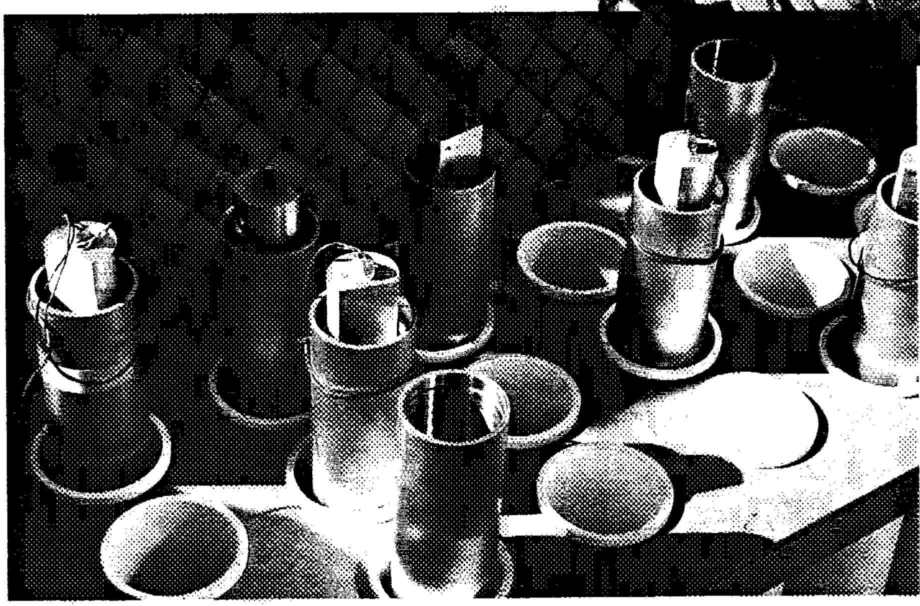
After trimming, the cured grains are bored to their final inside diameter in a special fixture.



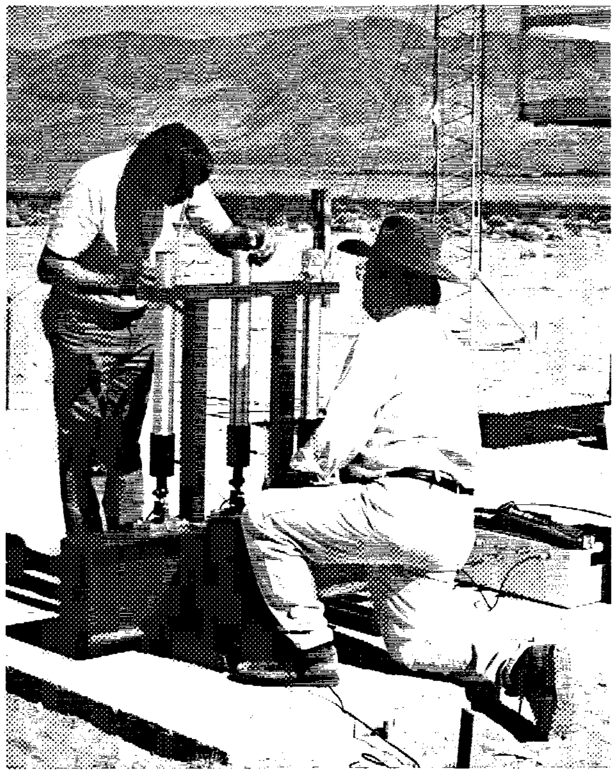
At left, a completed grain ready for final chamfering and installation in the motor case.

The cartridges are chamfered with a special tool as the final step in their preparation.

The instructors explain each step as the students start to assemble their motors for test.



Several student motors are stored in the ready rack awaiting transport out to the test stand for firing



Above; Three motors are set up in the test stand. Right and below; The moment of truth for each student. Several Mach diamonds are clearly visible in the exhaust plumes, but the camera cannot capture the sight and sound of such a test.