

Fundamentals of Solid Rocket Motors March 5 - 8, 2012

Course Description

This course is designed for engineers who wish to acquire an understanding of the fundamental concepts and basic analyses of solid motor performance. Lecture notes prepared by Dr. Gary Flandro will be provided.

About The Instructors

Dr. Gary A. Flandro is Boling Chair Professor of Mechanical Engineering at The University of Tennessee in Tullahoma, Tennessee. He has devoted over four decades to the study of oscillatory flow phenomena. He received his Ph.D. from California Institute of Technology in Pasadena, California under Professors Marble and Culick.

Dr. Fred E. C. Culick is the Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering and Professor of Jet Propulsion at the California Institute of Technology in Pasadena, California. He is the recognized international leader in solid rocket propulsion and combustion instability. He is a graduate of the Massachusetts Institute of Technology in Cambridge, Massachusetts.

Dr. Fred S. Blomshield is Head, Propulsion Research Branch at the Naval Air Warfare Center, China Lake, California. He is an expert in experimental methods and their application in combustion instability testing especially in nonlinear systems.

Mr. Paul Gloyer is President of Gloyer-Taylor Laboratories. He is a graduate of the University of Tennessee Space Institute in Tullahoma, Tennessee. He has several decades of experience with rocket motor design and development. He recently led a team of engineers that resolved a critical issue with NASA's Ares I launch vehicle that threatened to derail the lunar and planetary exploration program. He also led programs to develop propulsion systems for the PA-X suborbital rocket, the PA-E15k rocket engine, and the SPORT orbit transfer vehicle. He teaches courses in rocket propulsion at the University of Tennessee Space Institute.

Course Schedule

(NOTE: All Times are Central Time Zone)

Monday, March 5

8:00 a.m. Registration UTSI Lobby

8:30 a.m. Welcome

(8:30 - 4:00)

I. Fundamental Concepts

II. Nozzle Gas Flow

- A. Role of the Nozzle
- B. Governing Equations
 - i. Characteristics of Convergent-Divergent Nozzles
 - ii. Gas Flow in Rocket Motor Nozzles

III. Thrust of a Rocket Motor

- A. Momentum Thrust and Pressure Thrust
- B. Conditions of Optimum Thrust-Optimum Expansion
- C. Nozzle Divergence Losses
- D. Two-Phase Losses

Tuesday, March 6

(8:00 - 4:00)

IV. Solid Propellant Burning Rate

- A. Burning Rate Mechanism
 - i. Role of Heat Feedback
 - ii. Types of Solid Propellants
 - iii. Effects of Formulation Variable on Burning Rate
- B. Burning Rate Measurement Techniques
- C. Burning Rate Relationships
 - i. Effect of Pressure on Burning Rate
 - ii. Effect of Temperature on Burning Rate
 - iii. Effect of Crossflow-Erosive Burning
 - iv. Other Environmental Effects

V. Vented Vessel Equations

VI. Solid Propellant Rocket Motor Performance

- A. Performance Measurement
 - i. Motor Testing
 - ii. Performance Calculations from Test Results
- B. Solid Rocket Motor Preliminary Design
- C. Performance Prediction-the Solid Performance Prediction (SPP) Program

VII. Motor Ignition

- A. The Ignition Process
 - i. Conservation Equations
 - ii. Characteristic Delay Times
- B. Dynamic Burning
 - i. Ignition Peaks
 - ii. Extinction by Depressurization
 - iii. L* Instability

VIII. Nozzles

- A. Nozzle Design
 - i. Conical Nozzles
 - ii. Contoured Nozzles

B. Nozzle Structures

- i. Nozzle Components and Materials
- ii. Vectoring Nozzles
- iii. Construction Techniques
- iv. Thermostructural Analysis of Nozzles

Wednesday, March 7

(8:00 - 3:00)

IX. Propellant Formulation and Manufacture

- A. Energetic Considerations
 - i. Oxidizer/Fuel Ratio
 - ii. Stoichiometry
- B. Propellant Ingredients-Composite Propellants
 - i. Metallic Fuels
 - ii. Oxidizers
 - iii. Polymeric Fuel/Binders
- C. Propellant Ingredients - Minimum Smoke Propellants
 - i. Polymeric Monopropellant Binders
 - ii. Monopropellant Fillers
 - iii. Energetic Plasticizers
- D. Some New Energetic Materials Processing
 - i. Mixing and Casting Techniques
 - ii. Motor Processing
 - iii. Hazards Considerations

TOUR OF AEDC AT 01:00

Thursday, March 8

(8:00 - 4:00)

XI. Combustion Instabilities-Types, Causes, and Cures

- A. Acoustic Modes in Cavities
 - i. Standing Waves and Traveling Waves
 - ii. Acoustic Admittance at a Boundary (Walls)
 - iii. Effect of Combustion at Boundary
- B. Burning Rate Response to Pressure Fluctuations:
The Pressure-Coupled Response Function
- C. Erosivity Response to Velocity Fluctuations:
The Velocity-Coupled Response Function
- D. Pressure Oscillations in Solid Rocket Motors
 - i. Measurement of Propellant Response Function(s)
 - ii. Linear Stability Analysis
 - iii. Forced ("Noise-Driven") Oscillations
 - iv. Nonlinear Instability
- E. Some Real Examples

AEDC Tour Information

A tour of the Air Force's Arnold Engineering Development Center is scheduled for those attendees interested in the facilities and mission of the center. AEDC is the nation's premier aerospace ground flight test facility. The test facilities range from large wind tunnels and altitude jet and rocket test cells to space chambers, ballistic ranges, arc heaters and small research test cells. The center's unique test facilities simulate flight from sea level to space and from subsonic to hypersonic speeds approaching Mach 20.

In order to visit AEDC all participants must submit the following information:

1. Name, Place of Birth, Date of Birth and Citizenship (i.e. U.S., Canada, Japan, UK, etc.)
2. If citizenship is other than U.S. or participants hold dual citizenship please provide a LPR #, Visa # or Passport #. A color copy of the documentation must be provided 14 business days prior to the tour date.

Upon arrival at UTSI U.S. citizens may provide requested tour information. Foreign National information must be provided 14 business days prior to the tour date

It is very important that these instructions be followed, as no one will be permitted to tour without compliance and approval.

Please call the Continuing Education Office with any questions.

*Ph: (931) 393-7276
FAX: (931) 393-7433*

CERTIFICATES OF CONTINUING EDUCATION UNITS (CEUs) WILL BE PRESENTED FOR ATTENDING THIS COURSE. UTSI IS ABET ACCREDITED

Office of Continuing Education

Reservations may be made by using the registration form. The registration fee of \$1,649.00 includes all necessary supplies. Early reservations are recommended. Refund of registration fee can be made if cancellation notice is received ten working days prior to beginning of the course. Cancellation received less than **10 working days prior to the course** will be assessed 20% of the registration fee. Registration within the 10 working days prior to the course is also subject to the same cancellation policy. Substitution may be made at any time.

Please register by mail, fax, or telephone. A telephoned, mailed, or faxed reservation made **by an official training office** is considered a firm registration and cancellation policy will apply. A letter of acknowledgment will be mailed to the individual for whom the reservation is made, or to the training office, as we are instructed. Class size will be limited to ensure optimum interaction among participants. UTSI reserves the right to cancel the course. The liability of The University of Tennessee Space Institute is limited to the registration fee. UTSI will not be responsible for airline ticket cancellation fees or any other expenses incurred because of course cancellation. Enrollees will be notified and a full refund will be made. Late applicants will be considered on a space available basis.

The course is payable in advance and includes the cost of notes, classroom material, refreshments, and lunches. The fee does not include expenses for motel accommodations or other meals. Payment may be made by check, money order, or credit card. Be sure to include attendee name(s) and course title with check. Please make checks payable to The University of Tennessee Space Institute. **VISA, MasterCard, and Discover are accepted.**

UTSI reserves the right to substitute speakers in the event of unusual circumstances. UTSI does not sell the course notes. You must attend the course in order to receive the material. Training taken to maintain or improve professional knowledge and skills is usually tax-deductible. Consult your tax advisor. **Please notify us if you require special meals, wheelchair access, or other accommodations.** Casual dress is appropriate.

Enrollment may be made by individuals or companies. Any number of persons may enroll from a single organization so long as there are vacancies. We suggest that you phone us of your intention to enroll as soon as you initiate your organization procedure so we can hold a place for you and be better able to plan the arrangements. Phone the Continuing Education Director at (931) 393-7276 and then follow with the written application.

A place in the course will be reserved for industry personnel and government employees who require time to obtain authorization. Organizations may enroll for a given number of individuals, supplying the names at a later date, if necessary. For all such enrollments or reservations, the individual names should be received by the Institute as soon as possible to ensure a place in the course. For additional applications, use separate sheet giving all particulars required on the application form.