Office of Continuing Education

Reservations may be made by using the registration form. The registration fee of $1,575.00 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.

Registration Form

PLEASE - notify us if you require special meals, wheelchair access, or other accommodations.

Name: ______________________________

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Mail fee along with this form to:

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The University of Tennessee Space Institute
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B. H. Goethert Parkway
Tullahoma, Tennessee 37388-8897

Ph: (931) 393-7276
Fax: (931) 393-7433
Toll Free: 888 822-8874 ext. 276

❑ Basic Analytical and Numerical Methods for Propulsion and Aerodynamic Analysis of Solid-Propellant Rockets
March 22-March 26, 2010
Course Fee: $1,575.00
AIAA Member Course Fee: $1,417.50

METHOD OF PAYMENT

☐ Check or Money Order Payable to: **The University of Tennessee Space Institute**

☐ VISA ☐ MasterCard ☐ Discover

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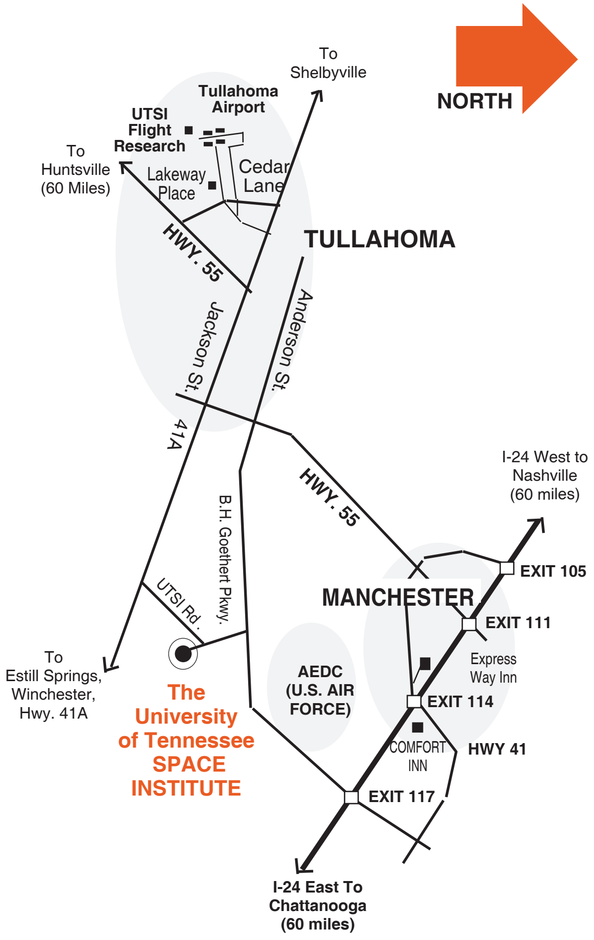
Signature Date

Location Map

UTSI is adjacent to the Arnold Engineering Development Center (AEDC) and can be reached from Nashville, Chattanooga, and Huntsville airports. Nashville and Chattanooga are approximately 75 minutes drive from UTSI. Huntsville is 95 minutes. Motels are located about 12 miles from the Institute. Military personnel and government employees may stay at the Arnold AFB VOQ located about 2 miles from the Institute. The Office of Continuing Education will assist with your reservations. Rental cars are available at airports.



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Short Course:
Basic Analytical and Numerical Methods for Propulsion and Aerodynamic Analysis of Solid-Propellant Rockets
March 22-March 26, 2010
www.utsi.edu

THE UNIVERSITY of TENNESSEE
Space Institute
Tullahoma, Tennessee

Office of Continuing Education offers

Basic Analytical and Numerical Methods for Propulsion and Aerodynamic Analysis of Solid-Propellant Rockets

Course is limited to U.S. Government and Its Contractors

Director:
Dr. Gary Flandro

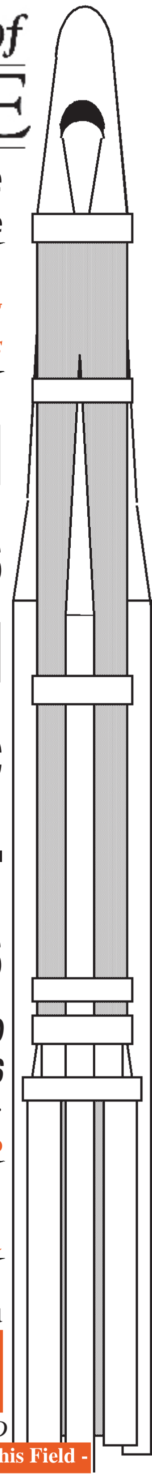
Lecturer:
Dr. Mark Salita

www.utsi.edu

March 22-March 26, 2010

EARLY RESERVATIONS ARE SUGGESTED

- Please Forward To Departments Working In This Field -



Basic Analytical and Numerical Methods for Propulsion and Aerodynamic Analysis of Solid-Propellant Rockets March 22-March 26, 2010

Course Description

The purpose of this course is to provide the rocket scientist/engineer with a sequence of analytical and numerical models from simple to complex to help solve the wide variety of problems that arise in the operation of solid-propellant rocket motors. Emphasis is placed on application rather than theory. The topics include both internal and external rocket environments, many of which also apply to liquid rockets (e.g. propellant combustion, nozzle flow, plume flow, external aerodynamics, and trajectory analysis). The attendee is assumed to have a basic knowledge of fluid mechanics and mathematical analysis. A CD containing Salita's book in both text format (500 pages) and lecture format (850 slides) will be provided.

Lecturer

Dr. Salita has more than 32 years experience modeling phenomena in and around solid-propellant rockets. He obtained a Master of Science degree in Aeronautics and Astronautics from Penn State University in 1967, and a PhD in Aerospace Engineering from the Guggenheim Labs at New York University in 1971. He worked on the Apollo propulsion systems during summer internships at the NASA Manned Spacecraft Center (now JSC) in 1966 and Langley Research Center in 1967. After working in Gas Turbine research for Pratt & Whitney (1972-1976), he joined Thiokol Corporation as Staff Scientist in Fluid Mechanics (1977-1992). From 1993 to 2008 he was a Senior Scientist at TRW/Northrop Grumman Missile Systems. He has developed the first models for many phenomena, including the operation of gas-bag inflators, O-ring erosion in booster joints, O-ring pressurization and activation, slag accumulation, and the size distribution of Al2O3 droplets formed from the combustion of aluminized solid propellants. He has chaired JANNAF Workshops in Solid Propellant Ignition, SRM performance, Slag Generation, and Vehicle Staging, and has written numerous papers for AIAA and CPIA. He has been an invited lecturer at AIAA short courses, NASA JPL, NAWC, Hill AFB, Onera, the von Karmen Institute, and the Technion.

Course Schedule

Monday, March 22 (8:00-4:00)

Chapter I: Introduction

What is a Solid-Propellant Rocket Motor?
Parameters Contributing to Thrust and Its Maximization
It All Starts with Chamber Pressure and Temperature
Basic Equations of Rocket Propulsion
Prediction of Vacuum Specific Impulse
Significance of the Pressure Integral
Methods for Determining Flight Performance
Potential Failure Mechanisms
Examples of Rocket Catastrophes
  Due to Failed Communication
Deficiencies of Many Analytical Codes
Operation of Computational Codes
Output Post-Processing
The Value of Closed-Form Solutions

Chapter II: Propellant Characteristics

Criteria for Good Solid Propellant
Propellant Ingredients and Formulations
AP Size Distribution
Elemental Mass and Mole Fractions of Ingredients
Propellant Heat of Formation
Mixing of Propellant Ingredients (Processing, Rheology)
Modeling the Flowfield During Propellant Mixing
Modeling the Casting Process
Propellant Burn Rate Law and Modifications
Propagation of Propellant Flaws (Cracks, Debonds, Voids)

Chapter III: Ignition of Solid Propellants

The Ignition Transient Phenomenon
  History of Modeling Efforts
  Sources of Ignition Transient Data
  Lessons from Hoop Strain Gage Data
  Grain Preheating and Ignition Criterion
  Measured Flame Spreading in Axial Fins
  Effect of Water Film on Propellant Surface
Flow Modeling
  Volume-Filling Equations of Chamber Pressurization
  0D Volume-Filling Model of Motor Ignition (VOLFIL)
  Deducing Chamber Temperature History from Known
  Pressure History
  1D Model of Motor Ignition (SHARPIT)
  Sample Case – Space Shuttle Booster
Effect of Grain Overhang, Case Expansion, Joint Rotation
Recommendations for Ignition Modeling
Pyrotechnic Igniters

Tuesday, March 23 (8:00 - 4:00)

Chapter IV: Combustion of Solid Propellants

Validity of Equilibrium Thermochemistry in Chamber
Properties of Two-Phase Mixtures
Equations of Chemical Equilibrium
Curve-Fitting of Thermochemical Properties of Combustion
  Species
Simple Example of a Closed Thermochemical Equation Set
Solution Procedure in Equilibrium Thermochemistry Codes
Sample Numerical Solution Using the NASA-Lewis Code
Transport Properties from Kinetic Theory
Equilibrium Surface Thermochemistry (Aerotherm,
  NASA-Lewis codes)
Approximate Closed-Form Solution for Chemical
  Equilibrium
Shock Jump Relations in Reacting Flow
Chapman-Jouget Detonations
Aluminum Combustion
  Size Distributions of Al2O3 Droplets in Chamber
  Summary of Experimental and Analytical Droplet Size
    Studies
  Quench Particle Combustion Bomb (QPCB)
  Laser Holography and Single Droplet Burning
  Dry Bomb and Helium Quench Motor

ChapterIV: Flow in the Combustion Chamber

Propellant Burn Back
  Cylindrical, Tapered, Endburning Grains
  Radially-Slotted Grains
  General 3D Grains with Axial Slots (Fins, Stars)
0D Quasi-Steady Flowfield in a Combustion Chamber
  "Ballistician's Equation"
  Effect of Deformation of Pressurized Grain
  Characterizing the Scatter in Flight Data
  Chamber Blowdown
1D Quasi-Steady Flowfield in a Combustion Chamber
  Shapiro Influence Coefficients
  Model Deduced from Hoop Strain Gage Data
2D Quasi-Steady Gas Flowfield in a Combustion Chamber
  Culick's Solution in a Cylindrical Chamber
  Flow in Cavity Behind Submerged Nozzle Using Water
    Analogs
  Incompressible and Compressible CFD Simulations
  Inhibitor Stubs: Flow/Structure Interaction
3D Quasi-Steady Gas Flowfield in a Combustion Chamber
  Effect of Axial Fins, Nozzle Gimbal, Asymmetric Stubs
3D Pressure Oscillations in Combustion Chambers
  Theory of Acoustic Oscillations in Cylind Chambers
  Oscillations Induced by
    Intersegment Slots and Inhibitor Stubs
    Propellant Corner and Coupled Sources
Two-Phase Chamber Flow
  Droplet Equations of Motion and Their Solution
  Slag Generation and Expulsion

Wednesday, March 24 (8:00 - 4:00)

Chapter VI: Nozzle Flow in Solid or Liquid Rockets

Geometry and Contour Optimization of Bell Nozzles
Nozzle Startup Process and Flow Analysis
1D Quasi-Steady Gas Flow in a Bell Nozzle
  Perfect-Gas Flowfield
  Gas Flowfield Assuming Equilibrium Chemistry
  Gas Flowfield Assuming Finite-Rate Chemistry
  Dynamics of Al2O3 Droplets Passing Through Nozzle
  Hermsen's Correlation for Droplet Size at Exit
2D Nozzle Flow
  Transonic Region
  Measured in JPL Nozzle
  Inviscid CFD Solution for Perfect Gas (NPARC)
  Inviscid CFD Solution for Two-Phase Flow (Chang)
  Supersonic Region
  Method of Characteristics for a Perfect Gas
  Numerical Solution from SPP/TD2P for Conical Nozzle
  Numerical Solution from TDK for Contoured Nozzle
  CFD Solution for Chamber and Entire Nozzle
  Nozzle Wall Effects (Flow Separation, Erosion,
    Liner Ejection)
3D Nozzle Flow
  Chang's Numerical Solution
  Scarfed Nozzles
  Thrust Vector Control (Vanes, LITVC)

Chapter VII: Heat Conduction and Material Ablation

Surface Boundary Conditions for Mat'l Heating/Ablation
Convective Heat Flux
  Reynolds Analogy
  Bartz Semi-Empirical Correlation
  Solution of 2D Differential Eqs for Thin Boundary
    Layers
  Solution of the Integral Eqs for Thin Boundary Layers
  Solution of the Parabolized Navier-Stokes Equations
  Solution of the Full Navier-Stokes Equations
Radiative Heat Flux
  Black Body Radiation
  Radiation from Hot Gaseous Species
  Radiation from Hot Condensed Species
  Closed-Form Solutions for Radiative Heat Flux
    in Uniform Cylindrical Media
1D Heat Conduction Solutions
  Numerical Solutions (Explicit, Semi-Implicit)
  Exact Analytical Solutions
Base Heating
  Convective Using CFD
  Gas Radiative (Analytical)
  Particle Radiative (RMC Code)
2D Heat Conduction (ABAQUS, HEAT2D, HERO2D)
2D/3D Heat Conduction and Radiation SINDA/G
Material Erosion
  Ablation Model for Non-Decomposing Materials
  Ablation Model for Decomposing Materials

Thursday, March 25 (8:00 - 4:00)

Chapter VIII: Launch Issues for Solid or Liquid Rockets

Diurnal Variation of Solar Heat Flux to a Launch Pad
Near-Fatal Ignition Overpressure During First Shuttle
  Launch (STS-1)
Ignition Overpressure During Silo Launch
Vehicle Staging
  Volume-Filling and CFD Simulations
  Nozzle Sideloads During Staging
  Experimental Sideload Data (Subscale, Full-Scale)
  Reduction of Nozzle Sideloads Due to Trip Rings
  Nozzle Failures Due to Sideload During Startup
  Sergeant's Model of Sideloads During Vehicle Staging
O-Ring Jet-Impingement Erosion (Pre-Challenger)
O-Ring Model of Deformation and Activation
Wind Shear: The Cause of Challenger
    and Columbia Accidents?

Chapter IX: Exhaust Plumes from Solid or Liquid Rockets

Low-Altitude (Mixing) Plumes
  Characteristics of Mixing Plumes
  Measured Centerline and Radial Decay
  Measured Droplet Size Distribution
  Location of Mach Disk
  Thermochemistry in Mixing Plumes
  Victor's Prediction Method for Nearly-Matched Plumes
  The JANNAF Standard Plume Flowfield Code SPF-III
    Matched Exit and the Effect of Afterburning
    Effect of Unmatched and Diverging Nozzle Exit
    Effect of Vehicle Velocity and Al2O3 Particles
Near-Vacuum (Non-Mixing) Plumes
  Method of Characteristics for Perfect-Gas Plumes
  Thermochemistry in Near-Vacuum Plumes
  Plume Boundaries for Conical Nozzles in Near-Vacuum
  Location of Mach Disk
  Near-Vacuum Particle Plumes
  Hill/Draper Far-Field Plume Flowfield Approximation
Plume Signature

Friday, March 26 (8:00 - 4:00)

Chapter X: Vehicle Aerodynamics

Definition of Vehicle Aerodynamic Coefficients
Analytical Methods
  Exact Solution for Supersonic Flow Past a Cone at Zero
    Pitch
  Numerical Solution for Supersonic Flow Past a Cone at
    Non-Zero Pitch
  Slender Body Theory
  Newtonian Theory
  Blunt Cones, Tangent-Ogives, Spheres
Component Buildup Methods:
  (Missile DATCOM, AP-98/05)
CFD Methods
  Nosetip Start Planes
  Supersonic Flow Past a Sphere
  Supersonic Inviscid Flow Past Bodies with or w/o Fins
  Subsonic/Supersonic Viscous CFD Past Arbitrary Bodies
Aero Coefficients in Free Molecular Flow