MASTER OF SCIENCE
IN
ASTRONAUTICAL ENGINEERING

IN-SITU MEASUREMENT OF TOTAL DOSE RADIATION EFFECTS ONARALLEL PLATE MOS CAPACITORS USING THE NPS LINEAR ACCELERATOR

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The study of radiation effects to electronics circuits has been ongoing almost as long as there have been satellites and spacecraft in space. The response to radiation over the planned life of the space system is of great concern to system designers. Operational amplifiers are one of the most basic elements in all electronic systems. This research examines radiation effects of part of a Metal Oxide Semiconductor (MOS) operational amplifier and is applicable to Complimentary MOS (CMOS) technology as well. More specifically, it is pertinent to MOS capacitors used to internally compensate op amps. First, a review of semiconductor theory is presented followed by a discussion of damage mechanisms to MOS capacitors and a brief look at operational amplifier fundamentals. MOS capacitors, constructed by previous research efforts using the MOSIS technique, were selected as the internally compensating elements for simple low pass filters. Using the Naval Postgraduate School linear accelerator, these capacitors were irradiated with pulsed electrons possessing energies of up to 26 MeV for varying times. In-situ measurements were taken to immediately determine the capacitance value via the measured filter break frequency as a function of fluence. Separate irradiation runs were performed on three MOSIS capacitors and were terminated upon filter failure. This research concludes with a hypothesis of the filter failure mechanism and suggested areas for expansion of continuing research efforts. This is believed to be the first time such an experiment has been performed.

STARTUP CONTROL OF THE TOPAZ-II SPACE NUCLEAR REACTOR

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The Russian designed and manufactured TOPAZ-II Thermionic Nuclear Space Reactor has been supplied to the Ballistic Missile Defense Organization for study as part of the TOPAZ International Program. A Preliminary Nuclear Safety Assessment investigated the readiness to use the TOPAZ-II in support of a Nuclear Electric Propulsion Space Test Mission (NEPSTP). Among the anticipated system modifications required for launching the TOPAZ-II system within safety goals is for a U.S. designed Automatic Control System. The requirements and desired features of such a control system are developed based upon U.S. safety standards. System theory and design are presented in order to establish the basis for development of a hybrid control model from available simulations. The model is verified and then used in exploration of various control schemes and casualty analysis, providing groundwork for future Automatic Control System design.

LAUNCH DETECTION SATELLITE SYSTEM ENGINEERING ERROR ANALYSIS

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An orbiting detector of infrared (IR) energy may be used to detect the rocket plumes generated by ballistic missiles during the powered segment of their trajectory. By measuring angular directions of the detections over several observa-

tions, the trajectory properties, launch location, and impact area may be estimated using a nonlinear least-squares iteration procedure. Observations from two or more sensors may be combined to form stereoscopic lines-of-sight (LOS), increasing the accuracy of the estimation algorithm. The focus of this research has been to develop a computer-model of an estimation algorithm, and determine what parameter, or combination of parameters will significantly affect on the error of the tactical parameter estimation. This model is coded in MATLAB, and generates observation data, and produces an estimate for time, position, and heading at launch, at burnout, and calculates an impact time and position. The effects of time errors, LOS measurement errors, and satellite position errors upon the estimation accuracy were then determined using analytical and Monte Carlo simulation techniques.

ANNEALING OF DEFECT SITES IN RADIATION DAMAGED INDIUM PHOSPHIDE SOLAR CELLS THROUGH LASER ILLUMINATION

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This thesis reports the results of a laser annealing technique used to remove defect sites from radiation damaged indium phosphide diffused junction solar cells. This involves the illumination of damaged solar cells with a continuous wave laser to produce a moderate heating and a large forward-biased current. The InP cells were irradiated with 27 MeV electrons to a given fluence, and tested for degradation. Light from an argon laser was used to illuminate each cell with an irradiance of 2.5 W/cm^2, producing a current density 7 to 10 times larger than under AM0 conditions. Cells were annealed at 48.5°C, 60°C, and 75°C for periods of 15 to 60 minutes, and cooled to 25°C for power recovery determination. Annealing at 48.5°C resulted in a recovery of 17 to 18% of the power lost due to irradiation, and annealing cells at 60°C produced a recovery of 43 to 48%. A single test of the technique at 75°C produced a net recovery of only 21% of the power lost. These results indicate that significant power recovery resulting from the annealing of defects within InP solar cells. Continuing research should involve the repeating of the test at 75°C, and irradiations with electrons or protons of energies expected in the space environment.

EXPERIMENTAL ANALYSIS OF THE WAKE OF AN OSCILLATING AIRFOIL

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The wake of an airfoil that oscillates in pure plunge mode is investigated in a water tunnel over a wide range of reduced frequency and amplitude. The main focus of this study is the comparison of the experimentally determined wake geometry with numerical results from a potential flow code. The wake vortices are visualized by two-color dye injection and velocity profiles are measured with LDV upstream and downstream of the airfoil. Wake signatures are examined with regard to thrust or drag generation. There is a good agreement between calculated and experimental data of the vortical wavelength. At high plunge velocities both approaches show a loss of wake symmetry and the emergence of a dual mode wake behavior.

OPTIMIZATION AND PERFORMANCE ANALYSIS OF WAVERIDER CONFIGURED INTERPLANETARY SPACE VEHICLES

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This thesis describes a number of issues associated with waverider configured spacecraft designed for interplanetary missions. The first such issue is the determination of the magnitude of the energies and velocities required for conventional gravity-assist (GA) spaceflight maneuvers contrasted with energies and velocities required for less conventional aero-gravity assisted (AGA) maneuvers for interplanetary spaceflight travel. These comparisons will be made for an Earth-Mars shuttle mission, a mission to Saturn, a mission to Neptune, and a round-trip mission to Saturn. Two additional issues considered for each mission are the fuel requirements and flight time parameters for both gravity-assist and AGA maneuvering spaceflight trajectories. This research includes the use of the patched conic interplanetary trajectory optimization MIDAS (Mission Design and Analysis Software) code for mission flight path analysis developed by the Jet Propulsion Laboratory. Waverider configuration development and off-design aerothermal analysis for each mission was supported by the NASA Ames Research Center's Waverider code (a subset of the Hypersonic Aircraft Vehicle Optimization Code) and a modified AEROSA code employing a Martian atmosphere, respectively. The results of this research showed that by using AGA, launch windows could be widened, flight times could be reduced by 25%, and fuels could be reduced by 30%.

CONVECTIVE HEAT TRANSFER FROM A CYLINDER IN A STRONG ACOUSTIC FIELD

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Experimental work was performed to study the convective heat transfer characteristics from a cylinder in a strong zero-mean oscillatory flow represented by an acoustic field. Two different flow regimes are discussed; that in which laminar, attached flow around the cylinder is present, and that in which instabilities, such as vortex shedding occur. The experiment utilizes a steady state measurement method. A transition from the laminar to the unstable regime was observed to occur at a streaming Reynolds number of approximately 240. Within the laminar regime, the transition from "intermediate" to "large" values of the streaming Reynolds number occurs at approximately 130. Heat transfer results for large values of the streaming Reynolds number in the laminar regime closely match the present theory (less than 13% error). Correlations were developed to relate the heat transfer rate to the streaming Reynolds number in the unstable regime. This work would find application in the design of heat exchangers for a thermoacoustic engine.

DESIGN, DEVELOPMENT AND TESTING OF THE ALL-REFLECTION MICHELSON INTERFEROMETER FOR USE IN THE MID-ULTRAVIOLET REGION

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The development of the Naval Postgraduate School's high resolution All-Reflection Michelson Interferometer has progressed into the mid-ultraviolet region. Two separate Mercury light sources, a pen-ray lamp and a germicidal lamp, were used to evaluate the performance of the instrument for the 2537 Å emission. The interferometer uses a pinhole aperture at the focus of an off-axis parabolic mirror to obtain a collimated input beam. A plane sinusoidal diffraction grating divides the beam into two orders. Planar mirrors reflect the beams back to the grating where they are diffracted again such that both beams are now in the plane of the detector. The beams recombine to form a linear interference pattern which is recorded by an ultraviolet detector. Data-reduction software coherently adds the interference pattern matrix and creates a doubled-sided interferogram. The spectrum is obtained by using Fourier Transform techniques. This compact, lightweight and economically produced interferometer has no moving parts. For this reason, the All-Reflection Michelson Interferometer is well suited for remote sensing of mid- to extreme-ultraviolet ionospheric emissions from a sounding rocket, space shuttle or satellite platform.

AN ANALYSIS OF GPS NAVIGATION SOLUTIONS FOR SHUTTLE MISSION STS-69

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The NAVSTAR Global Positioning System (GPS) has provided a quantum leap in real-time autonomous navigation capabilities. NASA's Space Shuttle will be receiving an integrated GPS capability in the near future, and the orbiter Endeavour has been equipped with a stand-alone GPS receiver. Although much data is available regarding spacecraft GPS receiver performance at higher altitudes, little information is available for spacecraft at Shuttle altitudes of approximately 400 km where drag and gravity effects are more pronounced.

GPS receiver navigation solution data from Shuttle mission STS-69 was made available by NASA and provided an opportunity for evaluating GPS performance in low Earth orbit. NASA ground tracking network and Tracking and Data Relay Satellite (TDRS) data for this mission provided a reference for comparison. Analysis of the data was accomplished using Satellite Tool Kit (STK) for visualization and Matlab routines for data comparison.

GPS navigation solutions were available for approximately 65 percent of the STS-69 mission, and they generally coincided with the reference track. Differences between the GPS navigation solution state vectors obtained using the Standard Positioning Service (SPS) and the reference state vectors produced RMS position differences between the data sets of about 1500 m. One sigma position accuracies of 54 m in the vertical direction and approximately 1400 m in the downtrack direction were experienced. Velocity vector magnitude differences during this period were generally ± 1 m/s, with a RMS velocity difference of less than 9 m/s. One sigma velocity accuracies of approximately 4.2 m/s in the vertical direction, 2.3 m/s in the downtrack direction and 1.5 m/s in the crosstrack direction were experienced. A firm conclusion regarding Shuttle GPS accuracies could not be drawn because all sources of error were not identified. Based on these results GPS appears to be an excellent navigation source for Shuttle state vector information; however, another navigation source such as INS must be present to provide a check against spurious data points and periods of outage.

THE EFFECTS OF PARTICULATES ON SUPERSONIC SHEAR LAYERS AND AFTERBURNING IN FUEL-RICH PLUMES

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An investigation was conducted to experimentally quantify the interaction of particulates with the fuel-rich plume flowfield typical for solid propellant rocket motors. This was done in order to optimize enhanced mixing devices or chemical-additive addition for afterburning suppression. Laser sheet flow visualization, sound spectra measurements, plume thermal images and particle size distribution measurements were utilized with reacting and non-reacting gaseous plumes and with the plumes from highly aluminized propellant and minimum smoke propellant. Several devices were evaluated for their effectiveness in providing increased mixing in the supersonic shear layer. It was found that the generation of axial vortices in the supersonic shear layers at the nozzle exit of rocket motors operating with characteristically high exit Mach numbers and high temperatures can enhance the mixing rates and affect the afterburning. The presence of large quantities of particulates both in the shear layer and in the plume core appears to significantly change the results obtained using enhanced mixing devices. Initial results with a ramp nozzle indicate that enhanced large-scale mixing can be provided in the presence of high particulate loadings in the plume.

OPTIMALITY OF AERO-ASSISTED ORBITAL PLANE CHANGES

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Future spacecraft designs, and in particular military spacecraft, may incorporate the use of synergetic orbital plane change maneuvers. The analysis of these maneuvers and their optimality is an area in which much work has been done but only a few questions have been answered. This thesis discusses the theoretical background for solving the optimal control problem. A framework is set forth for the formulation of the overall problem which must be solved. Pontryagin's Maximum Principle is applied to obtain the necessary conditions for maximizing the inclination change for a given amount of propellant. Effects of a heating rate constraint imposed by the thermal protection system are considered. The Program to Optimize Simulated Trajectories (POST) is used to obtain results for the Maneuverable Reentry Research Vehicle (MRRV) to illustrate certain points. Two characterizations of the atmospheric pass are analyzed and compared to previous work, namely Aerobang and Aerocruise. A discussion on the limited use of POST as a direct method of analysis is also included.

BURNING CHARACTERISTICS OF INDIVIDUAL ALUMINUM/ALUMINUM OXIDE PARTICLES

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An experimental investigation was conducted in which the burning characteristics of individual aluminum/aluminum oxide particles were measured using a windowed combustion bomb at atmospheric pressure and under gravity-fall conditions. A scanning electron microscope (SEM) was used to measure the size distribution of the initial aluminum particles and the aluminum oxide residue.

Analysis of the residue indicated that the mass of aluminum oxide contained in particles larger than 12 microns was less than 25 percent, in good agreement with data reported from aluminized solid propellant. The measured particle size distributions and photomicrographs implied that the burning aluminum particles periodically expel aluminum oxide fragments with sizes between 14 and 36 microns.

PROPELLANT FEED CONTROL FOR ION ENGINES

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An overview of space electric propulsion (SEP) is presented. Methods of throttling the power levels of electrostatic and electromagnetic thrusters are discussed. Particular attention is given to the concept of thermally-throttling propellant flow using the temperature-viscosity characteristics of xenon gas. The thermo properties of xenon gas as a function of temperature are determined, and the flow regimes of the propellant at the mass flow rates of interest are studied. The propellant flow is presented separately as Fanno flow and as Rayleigh flow, and then those combined effects are considered. A method for predicting the performance of thermally-throttled systems is presented. Uncertainties in modeling real-world thermal throttling systems are discussed. The possible use of thermal throttling characteristics as a means of propellant pressure regulation is also examined.

FLOW VISUALIZATION AND OPTIMIZATION OF SIDE-INLET-DUMP LIQUID-FUEL RAMJET COMBUSTORS

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Four variations of a single side inlet-dump ramjet combustor were examined using laser Doppler velocimetry and laser sheet flow visualization in a water tunnel. The baseline configuration was an inlet that dumped into the combustor at an angle of twenty degrees with respect to the combustor axis. The different inlet variations that were tested included an inlet aerogrid and two different scallop arrangements. The baseline combustor produced two large recirculation regions and large-scale structures shed from the dump plane. Very little fine-scale mixing was present. The flowfield would be conducive to combustion instability and low combustion efficiency. The aerogrid reduced the size of the recirculation regions, eliminated the large-scale vortices shed from the inlet dump and increased fine-scale mixing. These flow conditions would be conducive to high combustion efficiency and to minimum combustion instability, but may result in narrower flammability limits. Two different scalloped inlet arrangements were tested with the goal of providing the benefits of the aerogrid but with wider flammability limits and less pressure drop across the inlet. A geometry producing high-amplitude, low-frequency flow structure showed promise but further optimization is required.

LIQUID HYDROCARBON FUEL COMPOSITION EFFECTS ON PLUME CHARACTERISTICS

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An experimental investigation was conducted to measure the effect of commercially available fuel additives and mixture ratio on the sooting properties and the IR signature of a kerosene-oxygen rocket plume. Multiple wavelength light

extinction measurements were made together with measurements of the plume mid-IR signature. A Mie code was used to obtain the mean extinction coefficients as a function of the particle size distribution, complex index of refraction, and wavelengths of the collimated illuminating source. This initial investigation showed that the use of 0.6% by volume of Wynn's Emission Control Plus fuel additive in kerosene significantly reduced the plume soot concentration and radiance in the 3.5-5.0 µm IR band of a kerosene-oxygen rocket engine operating with an equivalence ratio of approximately 2.0. The size distribution and optical properties of the soot were not significantly altered. These initial results indicate that the mid-IR plume signature of kerosene burning rocket engines may be significantly altered using inexpensive, commercially available fuel additives. Further testing is required to examine wider ranges of engine operating conditions.

RECOVERY FACTORS IN ZERO-MEAN INTERNAL OSCILLATORY FLOWS

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High speed oscillatory flows, like high speed mean flows, are capable of inducing time-averaged heat transfer effects. This research involves the analytical solution of a model problem of zero-mean internal oscillatory flow, which arises from a high-intensity resonant standing acoustic wave set up across the ends of two parallel plates. The compressible form of the Navier-Stokes equations are solved, along with the equations of continuity, energy, and state, using perturbation solution and complex variable methods. MAPLE, a symbolic mathematical software tool, is utilized to find the time-averaged portion of the temperature distribution between the plates. The final heat transfer results are presented in terms of suitably defined recovery factors. The analysis is performed for varying gap widths between the plates using air as the host fluid. This work provides the fundamental explanation of the phenomenon responsible for the thermoacoustic refrigerating effect as well as an analytical basis for determining the optimum gap width between the plates of the stack in a thermoacoustic refrigerator.

PARTICULATE SIZING IN GAS TURBINE EXHAUST USING A LASER EXTINCTION TECHNIQUE

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The measurement of soot particulates densities in gas turbine engine and rocket exhausts is an area of continuing scientific investigation. Knowledge of exhaust plume soot concentration and sizing is critical for plume signature determination, currently a focus of theater ballistic missile defense research. This thesis research investigates the development and initial calibration of an instrument that will determine soot particle densities in an exhaust plume, by measuring the absorption of a light beam transmitted through the plume. This instrument utilizes an argon ion laser, four passes through the exhaust plume, and a phase conjugate crystal to correct for aberrations in the transmitted beam. Several aspects of instrument layout and performance were investigated, and an initial calibration against a conventional probe sampling technique was performed, using an ethelyne-air combustor as a soot source. While soot concentration measurements obtained with the instrument were internally consistent, the primitive sample probe used limited the opportunity to do an accurate comparison against a conventional method. The method requires further development, but shows significant promise for use in a jet engine test cell.

MASTER OF SCIENCE IN ASTRONAUTICAL ENGINEERING

VULNERABILITY OF INTELSAT/VSAT SYSTEMS
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This thesis considers the Navy's use of the International Telecommunications Satellite (INTELSAT) system with emphasis on the future utilization of Ku-band Super High Frequency (SHF) communications in the Navy's satellite communications architecture. In particular, it evaluates the use of very small aperture terminal (VSAT) networks in conjunction with the INTELSAT system. The scenario examined will be an hypothetical contingency operation with the U.S. Navy supporting a joint special operations force (JSOF) in a coastal region by providing communications, command, control and intelligence support using an INTELSAT/VSAT system.

The increased and mandated use of commercial satellite technology leads to a whole new arena of potential risks to exploitation. Critical vulnerability issues such as detection and interception, and anti-jamming will be addressed. This thesis is designed to aid the communications planner in his/her efforts to support the satellite communications requirements of the military end-user.

THE APPLICATION OF VIDEOGRAMMETRY IN THE STRUCTURAL TESTING OF SPACECRAFT
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This thesis will study the application of video photogrammetry in satellites and space systems. Industrial photogrammetry provides an extremely accurate and versatile means for non-contact, three-dimensional digitizing of a sample of points on an object of interest. Photogrammetry is non-invasive, because it measures photographic negatives of the object, not the object itself. Its flexibility and versatility are derived from photogrammetry's ability to view the object from many different angles in almost any test configuration. Using the process of optical triangulation the two-dimensional images from the different views are transformed into three-dimensional coordinate data. This data is then analyzed to provide the desired results. Tests were conducted during an experience tour at TRW Space and Electronics Division, Redondo Beach, California. The applications include a K-Biaxal unit rotation and orthogonality test, a boom stiffness test. The analysis will address the accuracy, versatility and adaptability, speed, and reliability of videogrammetry and compare it to other current test procedures such as linear variable differential transformers (LVDT) and strain gages.