DOCTOR
OF
PHILOSOPHY

INCORPORATION OF SWEEP IN A TRANSONIC FAN DESIGN USING A 3D BLADE-ROW GEOMETRY PACKAGE INTENDED FOR AERO-STRUCTURAL MANUFACTURING OPTIMIZATION

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A new 3D blade row geometry package was developed and implemented. In the new representation the blade is described by six Bezier surfaces two of which represent the pressure and suction surfaces with sixteen points each. The leading and trailing edges are each represented by two Bezier surfaces. Only one extra parameter is required (in addition to the pressure and suction surfaces parameters) to define each of the leading and trailing edge surfaces. Blade geometry manipulation in this format is easily implemented. A change to one surface location affects the surrounding area inversely proportional to the distance from the moved point, creating a smooth variation in geometry, free of waviness. The geometry generated is easy to handle with CAD/CAM programs without any conversion or approximation. The representation was applied to an existing transonic fan geometry to investigate effects of sweep. Results were obtained for the effect of forward and backward sweep on the aerodynamic performance, and the associated effect on centrifugal stress levels was obtained. The investigation demonstrated the suitability of the package to be incorporated into a multi-disciplinary design optimization process.

KNAPSACK CUTS AND EXPLICIT-CONSTRAINT BRANCHING FOR SOLVING INTEGER PROGRAMS

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Enhanced solution techniques are developed for solving integer programs (IPs) and mixed-integer programs (MIPs). Previously unsolvable problems can be solved with these new techniques. We develop knapsack cut-finding procedures for minimal cover cuts, and convert existing cut-strengthening theory into practical procedures that lift and tighten violated minimal cover valid inequalities to violated knapsack facets in polynomial time. We find a new class of knapsack cuts called “non-minimal cover cuts” and a method of lifting them called “deficit lifting.” Deficit lifting enables all of these cuts to be lifted and tightened to facets as well. Extensions of these techniques enable us to find cuts for elastic knapsack constraints and cuts for non-standard knapsack constraints. We also develop the new technique of “explicit-constraint branching” (ECB). ECB enables the technique of constraint branching to be used on IPs and MIPs that do not have the structure required for known “implicit constraint branching” techniques. When these techniques are applied to 84 randomly generated generalized assignment problems, the combination of knapsack cuts and explicit-constraint branching were able

to solve 100 percent of the problems in under 1000 CPU seconds. Explicit constraint branching alone solved 94 percent, and knapsack cuts solved 93 percent. Standard branch and bound alone solved only 38 percent. The benefits of these techniques are also demonstrated on some real world generalized assignment and set-partitioning problems.

A CASCADE APPROACH FOR STAIRCASE LINEAR PROGRAMS WITH AN APPLICATION TO AIR FORCE MOBILITY OPTIMIZATION

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We develop a method to approximately solve a large staircase linear program that optimizes decisions over time. Also developed is a method to bound that approximation's error. A feasible solution is derived by a *proximal cascade*, which sequentially considers overlapping subsets of the model's time periods, or other ordinally defined set. In turn, we bound the cascade's deviation from the optimal objective value by a *Lagrangian cascade* which penalizes unfeasibility by incorporating dual information provided by the proximal cascade solution. When tested on a large temporal LP developed for U.S. Air Force mobility planners, we often observe gaps between the approximation and bound of less than 10 percent, and save as much as 80 percent of the time required to solve the original problem. We also address methods to reduce the gap, including constraint extension of the *Lagrangian cascade*, as well as exploitation of dual multipliers within the proximal cascade.

SIMULATION OF THE DYNAMIC BEHAVIOR OF EXPLOSION GAS BUBBLES IN A COMPRESSIBLE FLUID MEDIUM

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Data from one-dimensional (spherically symmetric) analyses was used to examine the effects of compressibility and gas energy on the dynamic behavior of an explosion gas bubble, by comparing the bubble's behavior with experimental results and with analytical results which neglect these factors. Results from two-dimensional (axially symmetric) analyses were used to investigate the behavior of a deep explosion gas bubble in the vicinity of plane rigid or constant pressure boundaries. Previous analytical research into explosion gas bubbles near such boundaries has primarily led to results of a qualitative nature, owing to a complete breakdown of the assumptions made in the analysis at the critical juncture. In the present investigation, it was found possible to characterize the effect of the boundary surface on both the change in the first oscillation period of the bubble and its location at the end of the first oscillation cycle. For a broad range of bubble-boundary standoff distances, these semi-empirical characterizations have a functional form particularly suitable for extension of the quantitative results of this investigation to other explosive charge types, weights, and depths, as has been done for the Willis formula for the free-field oscillation period of explosion gas bubbles.

DOCTOR OF PHILOSOPHY

THE CONTROL OF BIFURCATIONS WITH ENGINEERING APPLICATIONS
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This dissertation develops a general method for the control of the class of local bifurcations of engineering interest, including saddle-node, transcritical, pitchfork, and Hopf bifurcations. The method is based on transforming a general affine single-input control system into quadratic normal form through coordinate transformations and feedback. (The quadratic normal form includes the quadratic order Poincare normal form of the uncontrolled system as a natural subset.) Then, linear and quadratic state feedback control laws are developed which control the shape of the center manifold of the transformed system. It is shown that control of the center manifold allows the quadratic and cubic order terms of the center dynamics to be influenced to produce non-linear stability. Specific matrix operations necessary to transform a general affine single-input control system into quadratic normal form are provided. Specific control laws to stabilize a general system experiencing a linearly unstabilizable saddle-node, transcritical, pitchfork, or Hopf bifurcation are also provided.

ON INTEGRATED PLANT, CONTROL AND GUIDANCE DESIGN
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Two theoretical methods and the development of a guidance, navigation and control rapid prototyping system address the issue of considering the integral participation of feedback early in the design process. The first method addresses the problem of sizing the horizontal tail on a statically unstable transport aircraft. Dynamic constraints including recovery from a severe angle of attack excursion and penetration of a vertical wind shear are formulated in terms of the solution to a convex minimization problem utilizing LMIs and used to size the horizontal control surfaces. The second method addresses the problem of tracking inertial trajectories with applications for unmanned air vehicles. This problem is posed and solved within the framework of gain scheduled control theory leading to a new technique for integrated guidance and control systems with guaranteed performance and robustness properties. Finally, a rapid prototyping system for the flight test of GNC algorithms for unmanned air vehicles is designed that affords a small team the ability to quickly take a new concept in guidance, navigation, and control from initial conception to flight test.

DOCTOR OF PHILOSOPHY

THE USE OF NON-PARAMETRIC TRANSFER FUNCTION ESTIMATES TO PREDICT SUBMARINE HULL VIBRATIONS FROM NOISE SOURCE MEASUREMENTS (U)

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Fundamental and practical limitations in the ability of non-parametric transfer function estimates to predict submarine hull vibrations are investigated. In order to assess the prediction performance and to succeed with non-stationary transfer functions, new methods and terminology are developed. An expression is derived for the maximum fractional error due to leakage which can be expected for the prediction of a pure sinusoid. For the data analysis, Bendat and Piersol's techniques for multiple-correlated inputs are used to condition up to eight input signals. Data is analyzed in three stages of complexity. The first data analyzed is from a scale model submarine driven by shakers. The next data is from the *USS Dolphin*, a deep-diving diesel-electric submarine. Measurements were taken on the Dolphin both surfaced running on diesels and submerged running on battery. During the submerged runs a minimal engineering line-up was used to limit the number of active noise sources. The final data analyzed was obtained from the *USS Hartford*, a nuclear attack submarine while in a normal engineering line-up. Results discussed include the percentage of power remaining in the processed hull signals, the lack of sensitivity of the predictions to input order, and the practical limitations encountered.

WAVELET ANALYSIS OF INSTANTANEOUS CORRELATIONS WITH APPLICATION TO FREQUENCY HOPPED SIGNALS

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Frequency hopped signals are widely used in various communication applications for their inherent security features. The demand, by civilian and governmental agencies, to intercept communication signals is increasing. The interception task can be summarized by detecting the signal's presence in additive noise, classifying the modulation type, estimating the control parameters, decoding the data, and decrypting the information content. This work addresses the merging of wavelet and correlation concepts to detect, classify, and estimate the parameters of frequency hopped signals. We address the interception problem in two ways. The first approach is based on a visual inspection of the wavelet surfaces generated from the instantaneous correlation function of the communication signal and leads to hop start/stop times estimates. In the second approach, we apply an energy-based processing scheme to estimate the hop start and stop times, the hop-scale pattern, and the hop frequency. Results show that frequency hopped signals can be identified at an SNR of 3 dB or 6 dB using visual inspection or an automated scheme, respectively.

DOCTOR OF PHILOSOPHY

AN ANNULAR THERMOACOUSTIC PRIME MOVER
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The dissertation constitutes the first detailed theoretical and experimental investigation of a thermoacoustic prime mover with periodic boundary conditions. There are five significant aspects to this research: (1) using DeltaE to analyze an annular prime mover, (2) developing an entirely new analysis program using MATLAB, (3) designing, building, and experimentally investigating a single stack, annular prime mover, (4) experimentally investigating a constricted, single stack prime mover, and (5) predicting the performance of a two stack annular prime mover. The major conclusions are: (1) A single stack annular prime mover will not reach onset because the eigenmodes of the system do not support thermoacoustic growth, (2) A constricted annular prime mover will reach onset because the constriction forces dominating boundary conditions that alter the eigenmodes, and (3) A two stack prime mover is predicted to reach onset because one of the eigenmodes of the symmetric system does support thermoacoustics.

AN EFFICIENT MODEL-BASED IMAGE UNDERSTANDING METHOD FOR AN AUTONOMOUS VEHICLE
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The problem discussed in this dissertation is the development of an efficient method for visual navigation of autonomous vehicles. The approach is to significantly reduce the expensive computational time of landmark detection by straight-edge features. A novel, fast straight-edge-detection method for use in autonomous vehicle navigation and other image-understanding applications is presented. Straight edges in gray-scale images are detected using a new *direction-controlled edge tracking method*, which gives precise estimate of the endpoints. To significantly reduce the number of exhaustive pixel computations, a *random-hitting method* using a pseudo-random number generator is proposed. Only if a generated pixel is significant do we start tracking the edge containing that pixel. To overcome the "noisy" gradient direction information, a robust least-squares linear fitting method is used to control the tracking process.

The results of the algorithm show how it is efficient for landmark detection, which is important for motion control of autonomous vehicles. Thus the new method is implemented as a component of the image-understanding system in the autonomous mobile robot Yamabico-11 at the Naval Postgraduate School.

An efficient world-modeling method based on the 2D model of the environment of the vehicle, including the heights of vertical edges in the environment, is presented. This modeling method is implemented with the new edge-detection method to improve the efficiency of the pose-determination algorithm (pose is a combination of the position and orientation of the camera), which is an essential task in the area of autonomous vehicle navigation.

DOCTOR OF PHILOSOPHY

INTERACTION OF LASER BEAMS WITH RELATIVISTIC ELECTRONS

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Motivated by the desire to put a free electron laser (FEL) weapon on a ship, the FEL and the related process of Compton backscattering are studied. The theme of the majority of this work is the interaction of the Gaussian optical mode with a beam of relativistic electrons.

Classical FEL theory is reviewed in Chapter II. Simulations based on the classical theory are used in Chapter III to study a proposed 1 kW (kilowatt) infrared FEL. In Chapter IV, simulation is used to study the problem of electron beam/optical mode overlap in an ultraviolet (UV) FEL. A new concept, the FEL with a short Rayleigh length, is studied in Chapter V. The idea is tested on the UV FEL, then used to design and simulate a megawatt-class FEL for ship self-defense.

An analytical calculation of the Compton backscattering of laser light is performed in Chapter VI. A quantum electrodynamics (QED) formalism is used to find the spectrum and angular distribution of photons scattered out of a Gaussian optical mode by relativistic electrons.

ANALYSIS OF MODAL TRAVEL TIME VARIABILITY DUE TO MESOSCALE OCEAN STRUCTURE

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This dissertation examines the effects of ocean mesoscale variability on acoustic arrival time patterns for two separate ocean environments. First, for an open ocean environment away from strong boundary currents, the effects of randomly phased linear baroclinic Rossby waves on acoustic travel time are shown to produce a variable overall spreading in the arrival pattern, primarily producing a delay in the later, axial arrivals. Second, using the state-of-the-art Semtner-Chervin eddy resolving global ocean circulation model coupled with the University of Miami Parabolic Equation (UMPE) acoustic propagation model, the effects of a fluctuating frontal region created by the California Current on the temporal, spatial and seasonal variability in the individual modal arrivals of the first thirty modes over a one-model-year time span is assessed. The mesoscale bias variability is also examined by comparing the various peak arrival times for the range-averaged environment to that of the range-dependent environment. To support this work, approximate “wide angle PE mode functions” were newly developed which form a different basis set for modal expansion from that obtained using standard normal mode theory. These new mode functions provide the proper basis set for modal expansion of the field computed by wide-angle PE models.

DOCTOR OF PHILOSOPHY

USE OF SHIP-MOUNTED ACOUSTIC DOPPLER CURRENT PROFILER DATA TO STUDY MESOSCALE OCEANIC CIRCULATION PATTERNS IN THE ARCHIPIELAGO DE COLON (GALAPAGOS ISLANDS) AND THE GULF OF THE FARALLONES

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Ship-mounted acoustic Doppler current profiler (ADCP data are used to study regional ocean patterns around the biologically rich regions of the Archipiélago de Colón (Galápagos Islands) and the Gulf of the Farallones to test the assumptions about the circulation derived primarily from hydrographic samples. West of the Galapagos, an equatorial undercurrent transport ~7 Sv was present in November 1993, which decelerated within 30 km of the archipelago, shoaled, and diverged with a strong deflection to the southwest. A method of removing tidal velocities from ADCP measurements by creating an empirical model of the tides and using it to predict and subtract the tides in described. It is shown that in the Gulf of the Farallones, a large number of observations, typically more than acquired on one cruise, are necessary to reduce tidal model error. Detided ADCP data are used to describe the circulation in the Gulf under various wind conditions. Over the continental slope, surface-to-depth poleward flow is present throughout the year. During wind relaxations, poleward flow strengthens and warmer, fresher water is transported onshore.

THE ASSIMILATION OF SATELLITE ALTIMETER DATA INTO A GLOBAL EDDY RESOLVING OCEAN MODEL

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Two assimilation experiments have been conducted using the Semtner/Chervin Parallel Ocean Climate Model at 1/4˚ resolution to investigate the dynamical changes which occur with the application of the nudging method to incorporate sea surface height observations (with associated vertical corrections to temperature and salinity) into a global eddy resolving ocean model. The first experiment used a previous model run as the observational field to determine if the assimilation technique, nudging, produced significant changes in the simulated fields to adjust the model to the observed fields when starting at a statistically different initial condition. The twin experiment has shown that the model does respond to the inclusion of the observed fields. Both the surface fields and subsurface fields have been adjusted towards these synthetic observations. The second experiment involved the use of a combined altimetric sea surface height anomaly field from the ERS-1 and the T/P satellites. The surface height fields are extended vertically by using the Levitus 94 monthly climatological fields. This dissertation has shown that assimilation of surface height data and an associated vertical adjustment to temperature and salinity, modifies both the surface and subsurface fields. Changes can be seen in both prognostic and diagnostic quantities (such as heat content and meridional overturning) while remaining dynamically consistent with the numerics of the model itself. Comparison of the simulated fields with in situ observations of temperature and salinity show that the model has adjusted towards observation not included in the assimilation process.

DOCTOR OF PHILOSOPHY

EXPERIMENTAL AND COMPUTATIONAL ANALYSIS OF SEPARATION BUBBLE BEHAVIOR FOR COMPRESSIBLE, STEADY AND OSCILLATORY FLOWS OVER A NACA 0012 AIRFOIL ($M\infty = 0.3$, $Re_c = 540{,}000$)

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In this thesis, the separation bubble behavior and its effect on the steady and dynamic stall characteristics of a thin airfoil in a compressible flow at a transitional Reynolds number was studied. For such flows, laminar separation occurs near the airfoil leading edge, but turbulent reattachment occurs within a short distance downstream, forming a separation bubble in the underlying region. Two experimental techniques, point diffraction interferometry (PDI) and laser doppler velocimetry (LDV), were used to acquire detailed flowfield information that showed the development of the leading-edge separation bubble and its subsequent bursting at higher angles of attack. The initiation of the stall process from the leading-edge separation bubble as opposed to trailing-edge flow reversal pointed to the need for transitional flow analysis. Both in the boundary layer and Reynolds-averaged, Navier-Stokes (N-S) analysis methods, transition models were incorporated to determine the location and extent of the transition zone that best modeled the measured separation bubble behavior. Computed results for steady flow gave remarkable agreement with the measurements. The computations compared favorably with the measurements for an airfoil oscillating in pitch about the quarter-chord point during the airfoil upstroke. However, the computations did not predict the light stall and vorticity-shedding process that was measured during the airfoil downstroke.

LOW ALTITUDE OPTICAL SIGNAL PROPAGATION OVER THE OCEAN

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The effects of ocean surface waves on optical signal fluctuations and optical refraction are evaluated. The effects on signal fluctuations were inferred from the ocean surface wave spectral density and temperature fluctuation spectral density. The effects of ocean waves on optical refraction are manifested in the near-surface gradient of the temperature profile. A modified temperature profile incorporating a statistical mixing length scale is proposed. The research points to the importance of certain parameters that should be considered when optical signals skim the ocean surface.

ELECTROMAGNETIC SCATTERING OF AN ANISOTROPICALLY COATED TUBULAR CYLINDER

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The sum-difference surface current formulation is introduced to treat electromagnetic boundary value problems when anisotropic impedances are specified on both sides of a surface. It can also be applied to impedance coated bodies. This formulation preserves the duality nature of Maxwell equations and carries it over into the algebraic form of the integrodifferential operators in the equations for surface currents. Since a 90° rotation is equivalent to undergoing a duality transform for an incident plane wave, this particular symmetry in the algebraic form of the operators leads to sufficient conditions under which the on-axis backscattering of an anisotropic impedance coated scatterer having a 90° rotational symmetry is eliminated. The sum-difference formulation is utilized for solving the problem of electromagnetic scattering

from an anisotropically impedance coated tubular cylinder of finite length. The solution has been coded in FORTRAN and tested. Some interesting results are presented and discussed.