MASTER OF SCIENCE
IN
AERONAUTICAL ENGINEERING

A COMPUTER CODE FOR RAPID CALCULATION OF BENDING FREQUENCIES OF ROTOR BLADES

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This thesis provides a MATLAB® code and graphical user interface (GUI) which rapidly estimates the bending frequencies of rotating beams from the knowledge of bending frequencies of nonrotating beams. The approach is based on the Rayleigh energy method developed by Yntema. The beams may be rotating or nonrotating, cantilever or hinged, uniform or with linear mass and stiffness distributions, with or without root offsets from the axis of rotation; or uniform with or without tip mass. Especially, the frequencies of both nonrotating and rotating cases can be estimated for (a) beams with and without offset which have mass and stiffness distributions which can be approximated by linear relations and (b) beams with uniform mass and stiffness distributions plus a concentrated mass at the tip. Also, as a part of the MATLAB® code, the bending frequencies of rotating beams with arbitrary stiffness and mass distributions can be estimated given that the stiffness and mass distributions as well as mode shapes of the rotating beam are provided. In latter case, the mode shapes of nonrotating beams may be used to get rough estimations. The code also presents the nonrotating bending-mode shapes in conjunction with the bending frequencies. The code and GUI are intended for use as a subprogram of JANRAD computer program developed at the Naval Postgraduate School, but can also be used as a stand-alone MATLAB® program.

KEYWORDS: Bending Frequency, Mode Shape, Rotating Beam, Nonrotating Beam, Rotor Blades, Rayleigh, MATLAB, JANRAD, GUI

DESIGN RECOVERY AND IMPLEMENTATION OF THE AYK-14 VHSIC PROCESSOR MODULE WITH FIELD PROGRAMMABLE GATE ARRAY TECHNOLOGY

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This study examines details surrounding design recovery of a legacy processor, and FPGA implementation of a binary compatible replacement processor. It targets the AN/AYK-14(V) Navy Standard Airborne Computer, specifically the XN-8 chassis mission computer used onboard today's F/A-18 C/D aircraft, as the design center piece. This mission computer was chosen not only because it provides a representative example of a blossoming legacy avionics challenge occurring today, but also because the AYK-14 is the focus of a study being conducted by the Naval Air Systems Command (NAVAIR) Advanced Weapons Laboratory (AWL). The core design of the AYK-14 VHSIC Processor Module was recovered through research of available documentation, and design improvements were made in an attempt to increase processing throughput. The improved design was modeled using VHDL, synthesized and functionally verified using commercially available simulation software. This study shows that replacement of complex legacy processors through use of FPGA technology is a viable option. These research efforts are primarily intended to benefit the AWL analysis, but its findings may prove useful for program managers throughout DOD.

KEYWORDS: Obsolescence, Legacy, Processor, FPGA, AYK-14, VHDL, VHSIC, Synthesis, Algorithm, State Machine, Clock, Bus, Pipeline, Data Path, Controller, Register, ALU, ASM Chart, Assembly Language, Instructions, Microcoding, CISC, Logic Cells, Xilinx, Synplify, Aldec, Xess, BRAM

INVESTIGATION OF DETONATION WAVE DIFFRACTION INTERACTION WITH REACTIVE TRANSPIRATION

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This thesis consisted of a design and development phase, and the subsequent testing of nozzle geometries. The first phase was composed of two parts, the design of a detonation tube with a divergent 2-D nozzle with optical access, and the implementation of fuel-air mixture injection through the divergent walls. The second phase consisted of investigating the feasibility of detonation wave propagation through the divergent 2-D nozzle while injecting reactive mixtures through the divergent walls.

During the design, care was taken to extend the optical access ports past the divergent walls, into the plenum chamber upstream of the injector plates. This was required to visualize the effects that a detonation wave passing through the divergent nozzle has on the flow behavior upstream of the injection holes.

Five configurations were investigated: 1) the solid injection plates along the divergent walls; 2) observation of the steady-state transpiration of a reactive mixture; 3) non-transpiring porous sidewalls; 4) non-reactive transpiration through the injector plates; and 5) reactive mixture transpiration.

Successful detonation wave transmission through the divergent 2-D nozzle was achieved in cases 1 and 3. Meanwhile, cases 4 and 5 failed to achieve a successful detonation transmission.

KEYWORDS: Detonation, PDE, PDEs, Pulse Detonation Engine, Detonation Diffraction

PROBABILISTIC MODELING AND SIMULATION OF METAL FATIGUE LIFE PREDICTION

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As fiscal constraints demand maximum utilization, engineers must develop more rigorous methods to predict the life limits of aircraft components. Current Navy policy requires that aircraft and aircraft parts be retired before they reach 100% FLE. An investigation has been initiated that would attempt to quantify the probability of failure if aircraft parts were extended in service life beyond 100% FLE.

The work of this thesis was to investigate the probability distributions of test data taken for aluminum 7050-T7451, and to attempt to develop a probability based model from the variation of the four fatigue life constants (s'_f, e'_f, b, c). The goal was to create strain-life-probability curves that would more accurately describe the likelihood of failure at a given strain amplitude.

The investigator determined that the test data did not demonstrate any consistent known probability density function. The investigator cautioned against assuming a normal distribution before it could be completely established as the predominate probability density function. Possible consequences of invalid assumptions were presented. Attempts were made to explain the disparity of sample data between two different laboratories testing of the same material.

Assuming random behavior within an established range, probability based models were developed using the four strain-life constants. It was determined that in order to create a complete probability based model, an accurate regression of the test data must fit all strain levels to include the intermediate strain level's "knee." In an attempt to solve that problem, eight parameter equations were explored. Methods to predict the eight parameters included random number simulation combined with non-linear least squares curve fits, evolutionary algorithms and genetic algorithms.

KEYWORDS: Metal Fatigue, Variable Strain-Life, Coffin-Manson, Monte Carlo Simulation, Service Life Extension, Evolutionary Algorithms, Genetic Algorithms, Aluminum 7050-T7451, Probabilistic Investigation

SYSTEM ASSESSMENT OF THE F/A-18 C/D AVIONICS ARCHITECTURE FOR LONG TERM SUPPORT AND FUTURE GROWTH

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The issue of legacy avionics in today's military aircraft is a very complex problem with unusual solutions. A military aircraft must be able to support future upgrades, but supportability issues are getting difficult because of the lack of funding to modernize the avionics. The F/A-18 Integrated Product Team (IPT) at the F/A-18 Advanced Weapons Laboratory has been tasked with supporting the F/A-18 aircraft, including maintenance and software support. The U.S. Navy has determined that some F/A-18 C/D configured aircraft will remain in service for the next 20 years. Foreign Military Sales (FMS) aircraft may remain in service for 30 years. In order to support these aircraft, the F/A-18 IPT desires an assessment of the C/D avionics system. This thesis will be part of the C/D avionics assessment by looking at the mission computers to determine their current throughput and their potential for future growth. This analysis will use a system timing tool developed by Boeing's MC Software Tools Group to collect data on mission computer I/O bus utilization and processor usage. The goal is to quantify the mission computers' current performance to better understand how to plan for future upgrades.

KEYWORDS: Avionics, AN/AYK-14, Computer Throughput, Avionics Architecture, F/A-18 C/D, System Timing Diagrams, F/A-18 Roadmap, Mission Computer

A FEASIBILITY STUDY OF OSCILLATING-WING POWER GENERATORS

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Mankind is continually searching for new sources of energy or methods to harness known sources. Recently, renewable and zero-pollution energy supplies are of great interest. Consequently, power generation from a fluttering wing is studied numerically and experimentally. Previous studies have suggested that an oscillating-wing used to extract energy from a fluid flow could deliver power comparable to windmills. Several studies are examined. An oscillating-wing power generator is designed and tested. The experimental results are compared with numerical predictions. Finally, commercial applications of the "environmentally friendly" oscillating-wing generator are investigated.

KEYWORDS: Oscillating-Wing, Flutter, Wingmill, Power Production, Power Extraction, Aerodynamics, Generator, Clean Energy, Numerical Modeling, Laplace, Navier-Stokes

DEVELOPMENT OF A MYKLESTAD'S ROTOR BLADE DYNAMIC ANALYSIS CODE FOR APPLICATION TO JANRAD

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Blade Dynamics Analysis is a major portion of a helicopter design. The success of the design is strictly related to accuracy of the blade dynamic calculations. The natural frequencies and the mode shapes are not only difficult to calculate but also can be a time consuming procedure. The Myklestad Extension Method gives the designer the opportunity of calculating correct values of the natural frequencies and the mode shapes when centrifugal forces are present. This thesis provides a transfer matrix Myklestad analysis programmed in MATLAB® and a Graphical User Interface (GUI) tool built in the MATLAB® programming language version 6.1, to implement the Myklestad Extension Method. The generated code and the GUI are designed to be a part of 'Blade Dynamics Module' of Joint Army/Navy Rotorcraft Analysis Design (JANRAD). For comparison, nonrotating and uniform beam data from Young and Felgar and the actual data of H-3 (S-61) helicopter blade are used. Results of the comparison show that the accuracy and robustness of the program are very good, which would make this generated code a valuable part of the helicopter designer's toolbox.

KEYWORDS: Rotor Blade Dynamics, Myklestad Extension Method, JANRAD, MATLAB, GUI, Natural Frequencies, Mode Shapes, Flatwise Axis, Edgewise Axis

FLAPPING-WING PROPULSION AS A MEANS OF DRAG REDUCTION FOR LIGHT SAILPLANES

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In this paper, flapping-wing propulsion as a means of drag reduction for light sailplanes is investigated numerically. The feasibility of markedly improving minimum sink and L/D_{max} performance parameters in light sailplanes by flapping their flexible, high aspect ratio wings at their natural frequencies is considered. Two propulsive systems are explored: a human-powered system that is used to partially offset airframe drag, and a sustainer system that uses an electric motor with sufficient power for limited climb rates. A numerical analysis is conducted using a strip-theory approach with UPOT (Unsteady Potential code) data. Thrust and power coefficients are computed for 2-D sections. 3-D spanwise load factors are applied to calculate total wing thrust production and power consumption. The results show that theoretical drag reduction in excess of 20%, and improvements of minimum sink by 24% are possible with a human-powered flapping system.

KEYWORDS: Flapping-Wing Propulsion, Drag-Reduction, Light Sailplanes

A 3D THEODORSEN-BASED ROTOR BLADE FLUTTER MODEL USING NORMAL MODES

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This thesis presents a fully coupled, quasi-3D analysis of rotor blade flutter that can accommodate forward flight conditions. The rotor blade is modeled as a uniform beam, taking the average characteristics of a real blade between 20% and 90% of its length. Applying Rayleigh's method, the first few bending and torsion

normal mode shapes and natural frequencies are calculated, and then adjusted for the rotating case. With this data, force and moment equations of motion are developed using LaGrange's equation along with a normal mode analysis. Theodorsen coefficients are calculated over a range of forward velocities (input as reduced frequencies) for a specified number of elements along the blade model. Incorporating these coefficients into the equations of motion, a square matrix is generated from which complex eigenvalues can be derived. These eigenvalues provide the aeroelastic natural frequencies and damping coefficients for each coupled mode. The forward velocity at which one of the modes produces a positive damping coefficient gives the value of reduced frequency for the flutter point. The resulting forward and blade tip velocities can then be determined.

KEYWORDS: Rotary Wing Structural Dynamics, Torsional Deflection, Bending Deflection, Rotor Blade Aeroelasticity, Theodorsen Lift Deficiency, Flutter Analysis, Helicopter Dynamics

STRAIN GAUGE MEASUREMENTS OF BLADE RESONANCE USING EDDY CURRENT EXCITATION IN A VACUUM SPIN PIT

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As part of an on going High Cycle Fatigue program related to gas turbine engines, which is sponsored jointly by the Naval Air Systems Command and the Air Force, unsteady strain gauge measurements were made on a 37.5 inch diameter titanium rotor in the Naval Postgraduate School, Turbopropulsion Laboratory vacuum spin pit. Vibratory excitation was produced by a number of evenly spaced magnets positioned around the rotor perimeter, which generated eddy currents in the blades and associated magnetic forces on the blade tips. A critical heating problem was experienced in initial tests, and instrumentation to monitor temperature of the metal passing within the magnetic field was installed. The first five runs following rework are reported. Correlations were made between temperature effects, magnet position, sweep rate, resonance amplitudes, and resonance frequency. An extensive evaluation was also performed of the strain data collection software, Data Physics Signal Calc 620.

KEYWORDS: Spin Pit, Eddy Current, Strain Gauge, Campbell Diagram, Order Analysis, Waterfall Analysis, Resistance Temperature Detector, Infrared Probe

DEVELOPMENT OF THE MATLAB-BASED MICHIN HELICOPTER AURAL DETECTION MODEL

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This thesis details the development of the helicopter aural detectability computer program MICHIN (MATLAB-based I Can Hear It Now). MICHIN is a MATLAB-based update of the United States Army's ICHIN6 (I Can Hear It Now) helicopter aural detection predictor. It accepts helicopter and ambient sound data, and then applies transmission losses, along with physiological characteristics of the human auditory system, to produce estimated detection range vs. frequency band output for a user-specified ambient condition. As an alternative to the original transmission loss calculations in ICHIN, MICHIN offers the option of importing data loss calculated by an external code, such as the U. S. Army's Scanning Fast-Field Program (SCAFFIP). This thesis reviews the theory and original development of the source program (ICHIN), explains refinements, and presents test results. Recommendations for further development are presented. Program listings, operation procedures, and evaluation data are given in the appendices.

KEYWORDS: Helicopter Detection, MICHIN, ICHIN, Rotor Noise, Aural Detection Range