MASTER OF SCIENCE
IN
AERONAUTICAL ENGINEERING

EXPERIMENTAL INVESTIGATION OF VORTEX SHEDDING IN FLOW OVER SECOND-GENERATION, CONTROLLED-DIFFUSION, COMPRESSOR BLADES IN CASCADE

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An investigation of vortex shedding downstream of a cascade of second-generation, controlled-diffusion, compressor stator blades, at off-design inlet-flow angles of 31, 33 and 35 degrees and Reynolds numbers, based on chord length, of 280,000, 380,000 and 640,000 is reported. The objective of the study was to characterize the flow and shedding through various complementary methods. Blade surface pressure measurements were taken from a fully instrumented blade, and distributions of pressure coefficients were determined. Five-hole probe wake surveys were performed at midspan, and the total pressure loss coefficients and axial velocity ratios were calculated. Upstream inlet-flow angle was set, and further characterized through two-component laser-Doppler velocimetry (LDV). Hot-wire anemometry measurements were performed at midspan, in the wake, and the reduced data was compared with two-component LDV surveys of the same regions. Plots of hot-wire vs. LDV turbulence data are reported in addition to power spectra documenting the shedding events.

Vortex shedding was determined to be a leading edge phenomenon as periodic shedding was only detected on the pressure side of the wake. The frequency and magnitude of shedding were found to be independent of incidence angle, and to increase with Reynolds number at constant incidence angle. The Strouhal number, based on leading edge diameter, was found to be in the range of 0.23-0.26, which is comparable to that of vortex shedding behind a circular cylinder in the Reynolds number range tested.

KEYWORDS: Controlled-diffusion, Compressor, Stator, Cascade, Turbomachinery, Hot-Wire Anemometry, Laser Doppler Velocimetry, Vortex Shedding

DESIGN AND RAPID PROTOTYPING OF FLIGHT CONTROL AND NAVIGATION SYSTEM FOR AN UNMANNED AERIAL VEHICLE

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This thesis seeks to design and implement an onboard flight control and navigation system for NPS FROG UAV using the newly marketed xPC Target Rapid Prototyping System from The Mathworks, Inc. The effort is in support of a larger research interest to implement command and control of a cluster of autonomous airborne vehicles with the capability to conduct coordinated flight maneuver planning and to perform distributed sensor fusion. Part I briefly introduces the aircraft and explains the necessity for an onboard computer for the UAV. Part II describes the construction of the miniature aircraft computer, INS/GPS and air data sensor integration implementation as well as the rapid prototyping process. Part III

covers the process to create a 6DOF model for the aircraft and the design of the aircraft autopilot, while Part IV presents a vision-based navigation algorithm that can be implemented on the UAV to give it some form of autonomous flight trajectory planning capability. Ground test results showing successful onboard data integration are given to conclude this report.

KEYWORDS: Unmanned Aerial Vehicles, UAV, Autopilot, xPC Target, Rapid Prototyping, Guidance and Navigation

RESONANT BLADE RESPONSE IN TURBINE ROTOR SPIN TESTS USING A LASER-LIGHT PROBE NON-INTRUSIVE MEASUREMENT SYSTEM

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Procedures to qualify turbo-machinery components for a designed lifetime free of high cycle fatigue (HCF) failures have not yet evolved. As part of an initiative to address this issue, in the present study, laser-light probes were used in a Non-Intrusive Measurement System (NSMS) to measure the unsteady deflections created in the blades of a second-stage turbine rotor in an evacuated spin pit. Air-jet and eddy-current excitation (ECE) methods were used to stimulate blade resonance. The NSMS was calibrated directly to gauge measurements of strain, and testing was conducted toward three additional goals; assessing the effectiveness of an advanced internal damping system; attaining higher excitation amplitudes with ECE by silver plating blades, and improving the repeatability of resonance data by adding plastic inserts between the fir-tree blade roots and the disk. It was concluded that the ability of NSMS to record the response of all blades is key to understanding the rotor system behavior and quantifying the statistical variability between blades.

KEYWORDS: Non-Intrusive Stress Measurement System, NSMS, Laser Light Probes, Hood Technology, Spin-pit, Magnet Excitation, Air-jet Excitation, XTE-66, Resonance

ANALYSIS OF A SEMI-TAILLESS AIRCRAFT DESIGN

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Many unique aircraft configurations came out of Germany in World War II, one of these was the Blohm and Voss BV P 208. By using longitudinal and directional control surfaces located outboard of the wing tips they are removed from the downwash of the main wing. Additionally, the result is fewer component surfaces with less total surface area, thereby reducing both friction and interference drag and manufacturing cost. The configuration should lend itself well to low-observability, making it a good stealth candidate. The P 208 provided the author an opportunity to analyze an unconventional configuration with the conceptual NASA design codes RAM, VORVIEW, and ACSYNT. A lack of wind tunnel or flight data prevented the evaluation of the performance of these codes for this configuration. However, results are presented for future comparison and evaluation. Claims of aerodynamic benefits of the P 208 configuration appear largely to be verified. The P 208 suffers from poor natural short-period longitudinal stability and an unstable Dutch-roll, neither of which are beyond the means of artificial control. The most immediate need for future work is a structural analysis and determination as to the structural and dynamic feasibility of the configuration.

KEYWORDS: Semi-tailless, P 208, RAM, VORVIEW, ACSYNT

MODELING THE OH-6A USING FLIGHTLAB AND HELICOPTER SIMULATOR CONSIDERATIONS

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Recent technological advancements in robust computer hardware, simulation modeling technology, newer electronic actuators and advanced computer graphics have enabled manufacturers to develop low cost, affordable helicopter flight simulators. This thesis presents detailed information on the U.S. Army Hughes OH-6A "Cayuse" helicopter together with a comprehensive model of the aircraft suitable for high fidelity simulator modeling. Fidelity of the model is obtained through use of commercial-off-the-shelf software that is incorporated in a low-cost flight simulator, which is marketed as FLIGHTLAB. The FLIGHTLAB development system facilitates rapid design and analysis of a high fidelity helicopter model using non-linear dynamic modeling techniques. The simulator model of the Hughes OH-6A helicopter is presented and its fidelity is compared to actual fight test data conducted at the U.S. Naval Test Pilot School in Patuxent River, MD. Advancements in electromagnetic actuators and visual rendering systems are also presented to provide insight into the direction simulator technology is progressing.

KEYWORDS: Modeling, Simulation, COTS

A NEURAL NETWORK APPROACH FOR HELICOPTER AIRSPEED PREDICTION

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Conventional pitot-static airspeed measurement systems do not yield accurate measurements when aircraft speed is below 40 knots. Recent studies have demonstrated that neural network approaches for predicting airspeed are quite promising. In this thesis, a back-propagation neural network is used to predict the airspeed of UH-60A and OH-6A helicopters in the low speed environment. The input data to the neural networks were obtained using the FLIGHTLAB flight simulator. The results obtained by flight simulation were validated by comparison to results of a previous study of the UH-60A helicopter based on actual flight data. The results of the work performed for this thesis show that at sea level the UH-60A low airspeed can be predicted with an accuracy of ± 0.71 knots and ± 0.88 knots for out of ground effect and in ground effect conditions respectively. OH-6A analyses were performed at two pressure altitudes. At sea level the OH-6A airspeed can be predicted with an accuracy ± 0.75 knots when the aircraft is out of ground effect and ± 0.88 knots when the helicopter is in ground effect. At a pressure altitude of 6000 feet OH-6A airspeed can be predicted with an accuracy of ± 0.64 knots for both flight conditions.

KEYWORDS: Airspeed Measurement, Neural Networks, Back-Propagation

ESTIMATION OF ROTOR BLADE TORSIONAL DEFORMATIONS FROM MEASURED BLADE TORSION MOMENTS

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The strain pattern analysis (SPA) method is applied to estimate rotor blade torsional deflections. The SPA technique requires calculated mode shapes for the tested rotor blade and strain measurements from the rotor's wind tunnel or flight test. The Holzer method is developed to calculate the required mode shapes from rotor blade stiffness and mass properties and the torsional equation of motion. The Holzer method is tested with numerous theoretical and experimental cases and is proven accurate. The strain measurements are from wind tunnel tests conducted by the Army, NASA, United Technologies Research Center (UTRC) and Sikorsky at DNW with a (1:5.73) model-scale UH-60A rotor blade with an advance ratio of 0.301, an advancing tip Mach number of 0.8224 and an average Reynolds number of 1,278,729. The SPA method predicts slightly larger torsional deflections that compare well with the overall trend and range of UTRC static method integrated deflections. The SPA method was evaluated to determine the tolerance to change in the number of measurements and the modes applied, errors in the measurements, and errors in rotor blade stiffness and mass properties. The method is tolerant to all effects except a decrease in the number of measurements and modes.

KEYWORDS: Rotor Wing Structural Dynamics, Torsional Deflection, Rotor Blade Aeroelasticity, Holzer's Method, Strain Pattern Analysis, Helicopter Dynamics