1999

HCF/SPIN TEST RESEARCH

R. P. Shreeve, Professor of Aeronautics & Astronautics
G. V. Hobson, Associate Professor of Aeronautics & Astronautics
Sponsor: Naval Air Warfare Center, Aircraft Division and NPS

OBJECTIVE: To investigate techniques for producing controlled blade excitation and measuring blade response which are suitable for high cycle fatigue (HCF)-related spin-testing and, when appropriate, to help transition those techniques to the Navy's Rotary Spin Facility at NAWCAD; also, to explore other HCF research opportunities.

SUMMARY: The "Spin-Pit" at the Turbopropulsion Laboratory has been overhauled and refurbished in order to provide a research facility in which to develop and transition techniques for HCF-related spin testing. Initial testing has been conducted using a large (M-1) rocket fuel-pump turbine rotor to re-establish test techniques and to measure shaft orbital motion. Spin hardware was designed and built for two test rotors, an 11-inch diameter transonic fan and a 37 inch (F119) fan. In collaboration with Hood Technology Corp., an eddy-current excitation technique will be used first, to excite resonant blade vibrations in the two rotors while rotating near centrifugal stress limits under vacuum. The capability to measure unsteady blade stresses using strain gauges and high-speed slip rings was developed. A PC-controlled, VXI-based real-time data system was assembled for, initially eight (extendable to 32) strain gauge channels. Software (ARMD) to predict the dynamics of spinning-rotor, shaft, bearing and damper systems, was installed and used to calculate the critical speeds of the first rotor system. A non-contact stress measurement system (NSMS), applied successfully on a low speed compressor (see 'Advanced Fan & Compressor Developmental Studies'), will be used in the blade-excitation tests of the large fan rotor.

ADVANCED FAN & COMPRESSOR DEVELOPMENT STUDIES

R. P. Shreeve, Professor of Aeronautics & Astronautics
G. V. Hobson, Associate Professor of Aeronautics & Astronautics
Sponsor: Naval Air Warfare Center, Aircraft Division

OBJECTIVE: To develop or validate tools for the design of advanced compression systems for Navy engines. Four tasks are ongoing: (i) to obtain experimental measurements and observations of CD blade stall for CFD code validation; (ii) to develop a geometry package geared to the design (by CFD analysis) of swept transonic blading; (iii) to install and test an advanced transonic axial stage, and thereby establish the means to economically evaluate more advanced designs; (iv) to develop advanced measurement capability.

SUMMARY: (i) Second-generation CD stator blading was re-tested, at three Reynolds numbers and off-design positive incidence angle, in a large rectilinear cascade, after the wind tunnel drive motor and blower were replaced [an NPS-funded facility upgrade after 25 years]. Small differences were found from data obtained in the initial tunnel configuration. A 3D LDV system was set up to map the downstream flow. A large-eddy simulation technique has been applied successfully to predict the flow at the two lower Reynolds numbers. (ii) A new Bezier-surface representation of axial transonic blading required only 32 control points and two parameters. Forward and aft sweep were introduced without changing blade shape, and the effect on aerodynamic performance and rotational stresses were determined. Emphasis is now shifted to experimental validation. (iii) The rebuilding of a CFD-designed transonic axial compressor stage, and associated test rig, is nearing completion. The flow through the complete stage was computed using Chima's SWIFT code. (iv) After developing the ability to make pressure-sensitive paint measurements on a transonic (disk) rotor, work was initiated to extract surface pressure and temperature from image data. Also, a two laser-light probe system was installed on a low-speed compressor, and blade vibration data were obtained successfully.

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OBJECTIVE: To develop or validate tools for the design of advanced compression systems for Navy engines. Three tasks are ongoing: (i) to obtain experimental measurements and observations of CD blade stall for CFD code validation; (ii) to develop a geometry package geared to the design (by CFD analysis) of swept transonic blading; (iii) to install and test an advanced transonic axial stage, and thereby establish the means to economically evaluate more advanced designs.

SUMMARY: (i) Second-generation CD stator blading has been tested in a large rectilinear cascade wind tunnel under near-stalling conditions, and LDV and flow visualization techniques were used to map and understand the flow field. The project was interrupted by the failure of the wind tunnel power supply, which has since been replaced. The data obtained at three different Reynolds numbers is being used to validate 3D Navier-Stokes code predictions, and preparations are being made to obtain similar data at an increased incidence angle. (ii) A Bezier-surface representation of axial transonic blading was found to require the specification of only 32 control points and two parameters. Forward and aft sweep were introduced without changing blade shape, and the effect of sweep on aerodynamic performance and rotational stresses were easily determined. (iii) An advanced transonic stage design was tested to 80% speed before a bolt failure led to the loss of the stage. The numerically-machined blisks and spinner were quickly replaced, and testing will resume when the build is complete. The ability to make pressure-sensitive paint measurements of the rotor blade surface pressure is being developed using a small turbine-driven disk rotor.

HCF/SPIN TEST RESEARCH

R.P. Shreeve, Professor of Aeronautics & Astronautics
G.V. Hobson, Associate Professor of Aeronautics & Astronautics
Sponsor: Naval Air Warfare Center, Aircraft Division

OBJECTIVE: To reactivate the Spin-Pit Facility at the Turbopropulsion Laboratory (TPL) and conduct a program to develop blade excitation and measurement techniques to be used on the Navy's Rotor Spin Facility at NAWCAD.

SUMMARY: The National High Cycle Fatigue (HCF) Initiative has identified a potentially important role for spin testing in the development cycle of new engines, and in eliminating HCF problems in existing engines. Blade-excitation techniques have been proposed for use in vacuum pits but no satisfactory system has yet been proven. The Spin-Pit Facility at TPL was reactivated in 1998 to enable blade excitation techniques to be evaluated and demonstrated at full scale. A technique proposed by Hood Technologies will be attempted first in 1999. Once proven, a practical system can be transitioned immediately to the Navy's production pits at NAWCAD. Close collaboration between NPS and NAWCAD is maintained. Related projects to support the Navy's participation in the HCF initiative are also explored.

UAV PROPULSION TECHNOLOGY

R.P. Shreeve, Professor of Aeronautics & Astronautics
G.V. Hobson, Associate Professor of Aeronautics & Astronautics
Sponsor: Unfunded

OBJECTIVE: To examine the potential performance of alternate engines for application in Predator and Global Hawk, and in other classes of UAV's.

SUMMARY: Reconnaissance missions require relatively low power and/or high altitudes. Current reciprocating engines do not have the reliability of gas turbines and can not use heavy fuel. An analytical study examined the potential impact of gas turbine engine variants on reconnaissance vehicles with emphasis on the recuperated gas turbine cycle. An on-going experimental study, using both turbocharger components and micro-gas turbine engines, seeks to establish performance characteristics of small gas turbines operating with JP fuel.

1996

FAN & COMPRESSOR STALL AND OFF-DESIGN PERFORMANCE IMPROVEMENT

G.V. Hobson, Associate Professor of Aeronautics & Astronautics
R.P. Shreeve, Professor of Aeronautics & Astronautics
Sponsor: Naval Air Warfare Center, Aircraft Division

OBJECTIVE: The overall goal of this continuing project is to validate off-design performance and stall prediction for controlled-diffusion (CD) compressor blading experimentally and thereby enable the development of higher blade-loading designs.

SUMMARY: LDV measurements of the flow through a second-generation CD cascade design were made at three different Reynolds numbers. The second-generation design is for twice the diffusion factor of the first-generation design, and includes an elliptic leading edge. The effect of Reynolds number on the formation of a midchord separation bubble was quantified. It was found that at a low Reynolds number of 210,000 a laminar separation bubble formed over the suction surface. At an intermediate Reynolds number of 380,000 the bubble was transitional, and at the high Reynolds number of 640,000, no midchrod separation was evident. However, at the high Reynolds number trailing edge stall was present as a result of three-dimensional flow developing because of the growth of corner vortices. The structure of the flow was defined using blade-surface pressure measurements, blade-surface flow visualization and laser velocimeter measurements, and was documented in the thesis by Schorenberg.

TRANSONIC FAN DESIGN VALIDATION

R.P. Shreeve, Professor of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center, Aircraft Division
& National Aeronautics and Space Administration

OBJECTIVE: This is continuing project to replace the single-stage fan currently installed in the transonic compressor test rig at the NPS Turbopropulsion Laboratory with a new stage designed by NASA with current CFD methods, and to evaluate all aspects of the aerodynamic performance using advanced intrusive and non-instrusive measurement techniques. The goals are to provide code vs. measurement comparisons using the new stage, to document a design-and-test case study for instructional purposes, and to develop a working facility and diagnostics for future studies.

SUMMARY: The transonic compressor test rig has been reactivated and operated successfully to 20,000 RPM. The design speed of the new rotor is 27,000 RPM. Since the front compressor bearing is showing high temperature and 1/Rev vibrations, balancing is required and this will be done with the new rotor installed. New VXI-bus data acquisition hardware was installed and software generation was initiated using HP-VEE. Significant progress was made in developing the pressure-sensitive paint (PSP) technique to map rotor surface pressures. A high-speed

turbine drive unit was installed and used to obtain phase-locked PSP data from a rotor operating at 20,000 RPM. Clearly defined in these tests was the temperature sensitivity of the paint technique. The turbine rotor is to be used to develop a procedure to identify surface pressure and temperature from phase-locked images.

UAV GAS TURBINE PROPULSION ASSESSMENT

R.P. Shreeve, Professor of Aeronautics & Astronautics

Sponsor: UAV Joint Projects & Demonstrations Directorate

OBJECTIVE: To conduct a program to provide information on the performance of small gas-turbine engines, and to generate the means to assess the potential for using gas turbines in UAV's.

SUMMARY: A small gas-turbine engine test rig was built and used to evaluate the performance a commercially-available, 17 pounds thrust engine. A performance code was used to simulate the measured performance and thereby allow probable component efficiencies to be deduced. The potential performance of a turboprop engine based on using the micro-gas turbine as a core was calculated assuming the same component efficiencies. Specific fuel consumption was found to be five times that of modern helicopter engines. The recuperative cycle was examined and advantages for small-scale engines were confirmed. A proposal was written to develop a performance code for recuperative engines to allow design studies for UAV missions.

1995

FAN & COMPRESSOR STALL AND OFF-DESIGN PERFORMANCE IMPROVEMENT

G.V. Hobson, Associate Professor of Aeronautics & Astronautics
R.P. Shreeve, Professor of Aeronautics & Astronautics
Sponsor: Naval Air Warfare Center, Aircraft Division

OBJECTIVE: The overall goal of this continuign project is to validate off-design performance and stall prediction for controlled-diffusion (CD) compressor blading experimentally and thereby enable the development of higher blade-loading designs.

SUMMARY: LDV measurements of the flow through first-generation CD blading at stall were repeated in the low-speed cascade wind tunnel (after repeated configuration changes) in order to fully validate a unique data set. A second-generation CD cascade design was then installed and LDV, surface pressure and loss data were obtained at the design flow-incidence angle. The second-generation design is for twice the diffusion factor of the first-generation design, and includes an elliptic leading edge. Separation behavior at leading and trailing edges are expected to be different, providing contrasting test cases for stall prediction.

TRANSONIC FAN CASCDE EVALUATION

R.P. Shreeve, Professor of Aeronautics & Astronautics
Sponsor: Naval Air Warfare Center, Aircraft Division
& Naval Postgraduate School

OBJECTIVE: To continue to develop the means to evaluate blade geometry effects and separation-control techniques in a fan-passage simulation model. This is required for the development of the efficient, lighter fans for military aircraft.

SUMMARY: In earlier work, a small, two-passage simulation of the flow on a stream surface through an advanced fan was developed using a blow-down wind tunnel incorporating back-pressure control, boundary layer diversion and porous-wall bleed control. Diagnostics included shadowgraph, fluid injection, surface pressures, and calibrated probe surveys downstream. In the present period, data were obtained for the losses and turning angle for blading with and without low-profile vortex generators positioned forward of the passage shock, and for old (after hours of testing) and new (chrome plated) blading. The design of a variable Mach number nozzle to allow experiments to be extended to higher Mach number, and to a larger scale was completed. Work was also continued to develop pressure-sensitive paint as a tool for shcok-boundary layer and similar studies.

TRANSONIC FAN DESIGN VALIDATION

R.P. Shreeve, Professor of Aeronautics & Astronautics
Sponsor: Naval Air Warfare Center, Aircraft Division & National Aeronautics and Space Administration

OBJECTIVE: This is continuing project to replace the single-stage fan currently installed in the transonic compressor test rig at the NPS Turbopropulsion Laboratory with a new stage designed by NASA with current CFD methods, and to evaluate all aspects of the aerodynamic performance using advanced intrusive and non-intrusive measurement techniques. The goals are to provide code vs. measurement comparisons using the new stage, to document a design-and-test case study for instructional purposes, and to develop a working facility and diagnostics for future studies.

SUMMARY: The transonic compressor test rig was reactivated. The bearing lubrication system, inlet throttle value and torque system were overhauled, and the rig was operated successfully to 20,000 RPM. Tests were suspended to change compressor bearings. The drive turbine unit will be operated at 27,000 RPM before installing the new compressor. In related work, a case study of the new stage design was initiated and the NASA compressor design code AXIDES was installed and used successfully on the Department's workstations. Also, toward the development of code-validation diagnostics for the new stage, a technique to record pressure-sensitive paint data from a high-speed rotor was developed using a dedicated test apparatus in the Gas Dynamics Laboratory.

UAV GAS TURBINE PROPULSION ASSESSMENT

R.P. Shreeve, Professor of Aeronautics & Astronautics
Sponsor: UAV Joint Projects & Demonstrations Directorate

OBJECTIVE: To conduct a program to provide information on the performance of small gas-turbine engines, and to generate the means to assess the potential for using gas turbines in UAV's.

SUMMARY: A small gas-turbine engine test rig was built and used to evaluate the performance a commercially-available, 17 pounds thrust engine. A performance code was used to simulate the measured performance and thereby allow probable component efficiencies to be deduced. The potential performance of a turboprop engine based on using the micro-gas turbine as a core was calculated assuming the same component efficiencies. Specific fuel consumption was found to be five times that of modern helicopter engines. The recuperative cycle was examined and advantages for small-scale engines were confirmed.

1994

TRANSONIC FAN CASCADE EVALUATION

R.P. Shreeve, Professor of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center, Aircraft Division (Trenton)

OBJECTIVE: To develop the means to evaluate blade geometry effects and shock-boundary layer interaction separation-control devices in a fan-passage simulation model. This is a necessary step in the development of more efficient, lighter weight fans for military aircraft.

SUMMARY: A pilot fan-passage simulation model has been built and operated in a small, M=1.4 blow-down cascade wind tunnel equipped with both inlet and back pressure control valves. Instrumentation includes 300 pressure taps over the lower blade section surface and end walls, a pitot survey probe downstream of the blading and shadowgraph-video photography. Flow incidence can be varied through model rotation. Tests have concentrated first on obtaining two-dimensional and periodic flow conditions in two blade passages with normal shocks in their design position, and obtaining repeatability in loss and static pressure distributions. Measurements with low-profile vortex generators are scheduled. Nozzle blocks have been design for M=1.7 and are in manufacture. A test section for tests at larger scale is being designed.

TRANSONIC FAN DESIGN VALIDATION

R.P. Shreeve, Professor of Aeronautics and Astronautics
N.L. Sanger, NASA Lewis Research Center
Sponsor: Naval Air Warfare Center, Aircraft Division (Trenton)

OBJECTIVE: To replace the single-stage transonic fan currently installed in a test rig at the Turbopropulsion Laboratory with a prototype design recently completed by NASA, and to evaluate all aspects of the aerodynamic performance by the application of advanced intrusive and non-intrusive diagnostics. The project goals are to provide code vs. measurement comparisons to validate current design and analysis codes, to develop practical unsteady measurement diagnostics for use in advanced fan development testing, and to complete a design test and evaluation case study for instructional purposes.

SUMMARY: The aerodynamic design of a single stage compressor for the NPS test rig was completed and will be reported this year. The mechanical design is also completed and procurement is planned in 1994. The low aspect ratio (1.2) stage has a diameter of 11 inches and tip relative Mach number of 1.3. However, because of unusually high blade loading, the overall stage pressure ratio is projected to be 1.56, at an efficiency of 90%.

FAN & COMPRESSOR STALL AND OFF-DESIGN PERFORMANCE IMPROVEMENT

G.V. Hobson, Associate Professor of Aeronatuics & Astronautics
R.P. Shreeve, Professor of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center, Aircraft Division

OBJECTIVE: The overall goal of this continuing project is to validate off-design performance and stall prediction for controlled-diffusion (CD) compressor blading experimentally and to obtain information necessary to the development of higher blade loading designs.

SUMMARY: The flow angle was increased to 50 degrees in a linear cascade wind tunnel containing CD compressor stator blading designed for an inlet air angle of nearly 40 degrees by Nelson Sanger. Intermittent stall was found to be present. Blade surface pressures indicated a drop off in normal force. Detailed LDV measurements were made ahead of, over the suction surface and in the wake of one test blade. Laser sheet flow visualization was used to video-record the unsteady stalling behavior and a qualitative correlation was obtained with the unsteady LDV data. These tests established stalling incidence and stall behavior of this well-documented blading design for the first time. Associated attempts to predict stalling using CFD codes were not completed.

1993

TRANSONIC FAN CASCADE EVALUATION

R.P. Shreeve, Professor of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center, Aircraft Division (Trenton)

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R.P. Shreeve, Professor of Aeronautics and Astronautics
N.L. Sanger, NASA Lewis Research Center
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FAN AND COMPRESSOR STALL AND OFF-DESIGN PERFORMANCE IMPROVEMENT

R.P. Shreeve, Professor of Aeronautics and Astronautics
G.V. Hobson, Associate Professor of Aeronautics and Astronautics
W.B. Roberts, Flow Applications Research
Sponsor: Naval Air Warfare Center, Aircraft Division (Trenton)

OBJECTIVE: The primary goal is to validate off-design performance and stall prediction for controlled diffusion (CD) compressor blading experimentally and obtain information necessary to enable development of higher blade loading designs.

SUMMARY: Two and three component laser-Doppler velocimetry (LDV), pressure probes, laser-sheet and surface flow visualization techniques are being used to obtain measurements through two designs of CD blading in a large (60 x 10 inch) recti-linear cascade wind tunnel. Measurements are compared with CFD viscous code calculations at progressively increased flow incidence angles. Suction has been installed to control wall boundary layers. First three-dimensional fiber-optic LDV measurements were made successfully and the corner vortices leaving the blading were mapped at eight degrees above design incidence. The high levels of turbulence found near the leading edges of the blading using LDV have been corroborated by recent hot-wire measurements. Refinement of the suction system to reduce inlet boundary layer thickness is planned before the second CD blade design (which has a much higher loading) is installed.

1992

TRANSONIC FAN CASCADE EVALUATION

R.P. Shreeve, Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Systems Command
Funding: Naval Postgraduate School

OBJECTIVE: To modify an existing supersonic blow-down wind tunnel to model the flow through the passages of an advanced engine fan, and to evaluate the use of passive separation alleviation techniques on the passage shock-boundary layer interaction at a relative Mach number of 1.7.

SUMMARY: Increasing relative Mach numbers are encountered as fan speeds are increased to obtain higher pressure ratios per stage. Separation, as the passage shock interacts with the boundary layer on the blade performance. The purpose here is to set up a relevant two dimensional experimental model in order to evaluate blade elements designed to incorporate separation control. The design of the test section and model will be based on a pilot experiment developed at M=1.4.

FAN AND COMPRESSOR STALL AND OFF-DESIGN PERFORMANCE IMPROVEMENT

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W.B. Roberts, Research Associate, Flow Applications Research
Sponsor: Naval Air Warfare Center, Aircraft Division, Trenton
Funding: Naval Air Warfare Center, Aircraft Division, Trenton

OBJECTIVE: Current tasks aim (1) to validate off-design performance and stall prediction for controlled-diffusion blading and obtain experimental information necessary to enable higher blade loading designs, (2) to develop the means to test shock-boundary layer alleviation devices for transonic fans.

SUMMARY: Previous tasks to measure the effects of tip clearance variation in a multistage compressor and to include secondary flow effects in throughflow code calculations were reported. Laser Doppler Velocimetry measurements in a large subsonic cascade wind tunnel containing controlled-diffusion blades at near-stalling incidence were augmented with laser-sheet flow visualization. New inlet guide vanes and suction for side wall boudnary layer thickness control were installed in preparation for tests at stall. A small scale two-passage model simulation of the flow through a transonic fan at M=1.4 was developed in a blow-down wind tunnel. Surface static pressure and wake impact pressure distributions were obtained and shadowgraph and fluid injection methods were applied to visualize the shock-boundary layer interaction. A numerical simulation was also obtained using the RVCQ3D code. The results provide a baseline for the evaluation of separation control techniques.