1998

TURBINE TIP-LEAKAGE FLOWS

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

OBJECTIVE: This project entails non-intrusive, laser-Doppler-velocimetry (LDV) measurements, in the endwall region of a turbine. The measurement technique was presented at the 33rd Joint Propulsion Conference, in Seattle (Ref. 1.). The specific turbine test article is the turbine of the High Pressure Fuel TurboPump (HPFTP) of the Space Shuttle Main Engine (SSME) and the particular hardware was designed and manufactured by Pratt & Whitney for NASA.

SUMMARY: An initial set of LDV measurements were taken in the tip leakage region of the turbine rotor. The turbine was relocated to the one side of the test cell to accommodate the two-component LDV. CDR. Southward also modified the turbine rig to include a closed-loop cooling water system for the dynamometer. This allowed for prolonged stable operation of the turbine, which was essential for the LDV measurements. The modification entailed the inclusion of a heat exchanger in the test cell and plumbing of the water lines from the plant air package water cooling system.

LCDR. McKee took over the project from CDR. Southward and had to rebuild the turbine rig as an overspeed of the turbine burnt out the bearings. LCDR. McKee repeated CDR. Southwards measurements and was about to increase the survey density when the Allis Chalmers Electric Drive Motor for the air supply system developed excessive vibrations. The motor had to be sent out for armature rebaring and rebalancing. Thirty five thousand dollars of NPS maintenance funds was used to perform the overall of this unique supply system (the motor is the drive for the air supply system for the High Speed Turbopropulsion Laboratory and is also used to drive the Transonic Compressor Rig). LCDR. McKee obtained three-hole probe measurements downstream of the rotor at different circumferential positions. These data plus the LDV data obtained were used for comparison with numerical predictions.

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. 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 completed. 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 the 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. One 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.

1997

TURBINE TIP-LEAKAGE FLOWS

G.V. Hobson, Asociate Professor of Aeronautics & Astronautics

Sponsor: Naval Air Warfare Center, Aircraft Division

OBJECTIVE: This project entails non-intrusive, laser-Doppler-velocimetry (LDV) measurements, in the endwall region of a turbine. The objective of the project is to transfer the measurement technique developed on an annular turbine cascade to an operational turbine test article.

SUMMARY OF WORK COMPLETED: The measurement technique was presented at the 33rd Joint Propulsion Conference, in Seattle. The specific turbine test article is the turbine of the High Pressure Fuel TurboPump (HPFTP) of the Space Shuttle Main Engine (SSME) and the particular hardware was designed and manufactured by Pratt & Whitney for NASA.

The project during 1996-1997 consisted of the upgrade the water cooling system of the HPFTP so that longer run times can be achieved. This will entail the commissioning of the new closed loop water cooling system on the dynamometer. The next task to perform LDV measurements in the rotor of the turbine for the HPFTP. The first task was successfully completed and the turbine has run continuously for extended periods of time with no recirculating water problems. The turbine was also moved closer to the side wall of the test cell to accommodate the standard optics LDV system. The moved entailed lengthening the inlet piping to the turbine. A picture of the new arrangement can be viewed at the Turbopropulsion Laboratory homepage (http://www.aa.nps.navy.mil/~garth/HPFTP3.gif). The second task was initiated with the successful installation of the LDV in the test cell. Continuous LDVL measurements have been over the turbine rotor in its tip region.

1996

FAN & COMPRESSOR STALL AND OFF-DESIGN PERFORMANCE PREDICTION

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

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

SUMMARY: Off-design performance of second-generation controlled-Diffusion blades was considered during this project. Extensive laser-Doppler velocimetry measurements were performed over the blade surfaces at three different Reynolds numbers. 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 midchord separation was evident. However; at the high Reynolds number trailing edge stall was present as a result of three-dimensional flow due to the growth of the corner vortices. Comparisons were made between blade-surface pressure measurements, blade-surface flow visualization and laser measurements in the thesis by Schorenberg.

TURBINE TIP-LEAKAGE FLOWS

G.V. Hobson, Associate Professor
Sponsor: NAWC Aircraft Division, Patuxent River

OBJECTIVE: The objective of this project is to develop techniques necessary to obtain non-intrusive laser-Doppler velocimetry (LDV) data in the tip-leakage region of operating turbines, as these flows account for significant losses. The problems associated with optical access windows, and seeding material have been addressed in an annular turbine cascade (ATC). LDV measurements will be performed in the turbine of the High Pressure Fuel TurboPump (HPFTP) for the Space Shuttle Main Engine (SSME).

SUMMARY: This project entails the measurement of complex turbine tip-leakage flows in test articles of small size at realistic Mach numbers. LDV measurements were performed in the endwall region downstream of the blade row within the ATC. These measurements were performed through a pressurized aerodynamic window. The effect of pressurization behind the aerodynamic window was quantified, particularly its effect on the LDV measurements. Comparisons with conventional probe measurements were performed.

TURBINE TIP-LEAKAGE FLOWS
G.V. Hobson, Associate Professor
Sponsor: NAWC Aircraft Division, Patuxent River

OBJECTIVE: The objective of this project is to develop techniques necessary to obtain non-intrusive laser-Doppler velocimetry (LDV) data in the tip-leakage region of operating turbines, as these flows account for significant losses. The problems associated with optical access windows, and seeding material have been addressed in an annular turbine cascade (ATC). LDV measurements will be performed in the turbine of the High Pressure Fuel TurboPump (HPFTP) for the Space Shuttle Main Engine (SSME).

SUMMARY: This project entails the measurement of complex turbine tip-leakage flows in test articles of small size at realistic Mach numbers. LDV measurements were performed in the endwall region downstream of the blade row within the ATC. These measurements were performed through a pressurized aerodynamic window. The effect of pressurization behind the aerodynamic window was quantified, particularly its effect on the LDV measurements. Comparisons with conventional probe measurements were performed.

1995

FAN & COMPRESSOR STALL AND OFF-DESIGN PERFORMANCE IMPROVEMENT

G.V. Hobson, Associate Professor
R.P. Shreeve, Professor
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 first-generation CD blading at stall were repeated in the low-speed cascade wind tunnel (after repeated configuration changes) in order to 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.

SPACE SHUTTLE MAIN ENGINE TURBINE PERFORMANCE MEASUREMENTS

G.V. Hobson, Associate Professor
Sponsor: Naval Postgraduate School

OBJECTIVE: This research project is aimed at obtaining performance measurements in a turbine for the High Pressure Fuel TurboPump (HPFTP) of the Space Shuttle Main Engine (SSME). Eventually the aim is to be able to measure the tip leakage vortex flowfield in the turbine with a three-component laser-Doppler velocimeter (LDV).

SUMMARY: The data acquisition system in the high speed building of the TPL was upgraded to a PC-based graphical system. With this extensive data acquisition system, performance measurements were performed on the turbine. These included turbine exit probe surveys and throttle valve control via the data acquisition system. The project also included the design and manufacture of the exit throttle valve for the turbine.

TURBINE TIP-LEAKAGE FLOWS

G.V. Hobson, Associate Professor

Sponsor: NAWC Aircraft Division, Patuxent River

OBJECTIVE: The objective of this project is to develop techniques necessary to obtain non-intrusive LDV data in the tip-leakage region of operating turbines, as these flows account for significant losses. The problems associated with optical access windows, and seeding material are to be addressed in an annular turbine cascade (ATC), and then LDV measurements will be performed in the turbine of the High Pressure Fuel TurboPump (HPFTP) for the Space Shuttle Main Engine (SSME).

SUMMARY: This project entails the systematic measurements of highly swirling turbine flows, with a three-component fibre-optics laser Doppler velocimeter (LDV), in test articles of small size at realistic Mach numbers.

Accomplished this year were blade surface pressure measurements in the cascade at various pressure ratios from subsonic to sonic exit conditions. Comparisons were made between these measurements and with a full 3-D CFD simulation of the flowfield. Detailed LDV measurements were performed in the endwall region downstream of the cascade, at a subsonic exit Mach number. These measurements were also through a 1 mm hole in the outer casing, at increasing radial depths and at different circumferential positions.

FAN & COMPRESSOR STALL

G.V. Hobson, Associate Professor

Sponsor: NAWC Aircraft Division, Patuxent River

OBJECTIVE: To perform detailed laser-Doppler-velocimetry (LDV) measurements in a low speed cascade tunnel of controlled-Diffusion (CD) compressor blades at stall.

SUMMARY: LDV measurements were repeated in the cascade of CD blades at stall. These measurements were performed after the tunnel had been reconfigured twice. The purpose of repeating the experiment was to determine whether the stall situation in the tunnel could once again be simulated.

These measurements ended more than a decade of testing on these blade which allowed a new set of second-generation CD blades to be installed in the tunnel. Initial design point operation measurements of the blade performance were obtained.

Initial test on a set of second generation CD blades were completed at design conditions. These entailed LDV, loss and blade surface pressure mesurements.

SPACE SHUTTLE MAIN ENGINE TURBINE PERFORMANCE MEASUREMENTS

G.V. Hobson, Associate Professor

Sponsor: Naval Postgraduate School

OBJECTIVE: This research project is aimed at obtaining performance measurements in a turbine for the High Pressure Fuel TurboPump (HPFTP) of the Space Shuttle Main Engine (SSME). Eventually the aim is to be able to measure the tip leakage vortex flowfield in the turbine with a three-component laser-Doppler velocimeter (LDV).

SUMMARY: The data acquisition system in the high speed building of the TPL was upgrade to a PC-based graphical system. With this extensive data acquisition system, performance measurements were performed on the turbine. These included turbine exit probe surveys and throttle valve control via the data acquisition system. The project also included the design and manufacture of the exit throttle valve for the turbine.

TURBINE TIP-LEAKAGE FLOWS

G.V. Hobson, Associate Professor

Sponsor: NAWC Aircraft Division, Patuxent River

OBJECTIVE: The objective of this project is to develop techniques necessary to obtain non-intrusive LDV data in the tip-leakage region of operating turbines, as these flows account for significant losses. The problems associated with optical access windows, and seeding material are to be addressed in an annular turbine cascade (ATC), and then LDV measurements will be performed in the turbine of the High Pressure Fuel TurboPump (HPFTP) for the Space Shuttle Main Engine (SSME).

SUMMARY: This project entails the systematic measurements of highly swirling turbine flows, with a three-component fibre-optics laser Doppler velocimeter (LDV), in test articles of small size at realistic Mach numbers.

Accomplished this year were blade surface pressure measurements in the cascade at various pressure ratios from subsonic to sonic exit conditions. Comparisons were made between these measurements and with a full3 – CFD simulation of the flowfield. Detailed LDV measurements were performed in the endwall region downstream of the cascade, at a subsonic exit Mach number. These measurements were also through a 1 mm hole in the outer casing, at increasing radial depths and at different circumferential positions.

1994

THREE DIMENSIONAL FLOWS IN AN ANNULAR TURBINE CASCADE

G.V. Hobson, Associate Professor

Sponsor: Naval Postgraduate School

OBJECTIVE: This research project is aimed at obtaining detailed three-dimensional viscous flow measurements in an annular turbine cascade (ATC). Eventually the aim is to be able to measure the vortex flowfield downstream of a turbine cascade which has formed as a result of tip leakage.

SUMMARY: Three-component LDV measurements have been performed in the corner cortex flow of the Low Speed Cascade (Ref. 1). LCDR. Spitz performed preliminary two-component measurements in the ATC. These LDV measurements compared well with previous three-hole probe measurements, however; the measurement location was not readily determined. LCDR Spitz also predicted (later verified by experiment) the blade surface pressure distribution with a three-dimensional Navier-Stokes code. Lt. Donovan has performed blade surface pressure measurements at various pressure ratios (up to the maximum mass flow rate or choking condition) and compared these distributions to full three-dimensional viscous flow calculations. He is currently setting up the tunnel to perform LDV measurements in the wake region. He will initially be repeating LCDR Spitz's measurements to accurately determine the measurement location.

TURBINE TIP-LEAKAGE FLOWS

G.V. Hobson, Associate Professor

Sponsor: NAWC Aircraft Division, Patuxent River

OBJECTIVE: The objective of this project is to develop techniques necessary to obtain non-intrusive LDV data in the tip-leakage region of operating turbines, as these flows account for significant losses. The problems associated with optical access windows, and seeding material are to be addressed in an annular turbine cascade (ATC), and then LDV measurements will be performed in the turbine of the High Pressure Fuel TurboPump (HPFTP) for the Space Shuttle Main Engine (SSME).

SUMMARY: This project entails the systematic measurements of highly swirling turbine flows, with a three-component fibre-optics laser Doppler velocimeter (LDV), in test articles of small size at realistic Mach numbers. The turbine of the High Pressure Fuel Turbopump for the Space Shuttle Main Engine was successfully commissioned into the turbine test rig at the Turbopropulsion Laboratory and preliminary performance measurements were performed, during this study. During these runs the turbine attained a maximum speed of 9600 rpm (design speed is approx. 7500 rpm). The design of a new outer casing for the turbine with optical access windows is currently underway. The configuration will be similar to the one used in the ATC. Currently the turbine is being overhauled after being dismantled for inspection purposes. The rebuild will include the new outer casing with the LDV windows, so that those measurements can commence.

1993

TURBINE TIP-LEAKAGE FLOWS

G.V. Hobson, Associate Professor

Sponsor: NAWC Aircraft Division, Trenton

OBJECTIVE: This project entails the systematic measurements of highly swirling turbine flows with a newly commissioned three-component fibre-optics laser Doppler velocimeter (LDV), in test articles of small size at realistic Mach numbers. The objective of the project is to develop techniques necessary to obtain non-intrusive LDV data in the tip-leakage region of operating turbines, as these flows account for significant losses. The problems associated with optical access windows, and seeding material are to be addressed in an annular turbine cascade (ATC), and then LDV measurements will be performed in the turbine of the High Pressure Fuel TurboPump (HTFT) for the Space Shuttle Main Engine (SSME).

SUMMARY: The design of the ATC was completed by Lt G. Thomas. Successful probe measurements were performed downstream of the annular turbine cascade. These entailed three-hole cobra probe measurements of total pressure, local Mach number and flow angle over one blade pitch and at seven different radial positions. Before the tunnel was complete, Lt. G. Thomas has successful run RVC3D (Rotor Viscous Code 3-D by Rod Chima of NASA Lewis research Center) on the ATC geometry. Initial *predictions* (before the tunnel was completed) showed that a wall jet was to form close to the hub endwall downstream of the blades. These results were unexplained and thus considered to be suspect, as they did not show the more familiar wake flow profiles, which were predicted for the rest of the annulus. Hwever; the initial probe measurements showed that these predictions were correct as the wall jet was a result of the secondary flow energizing the hub wall boundary layer. LDV measurements are planned in the coming year. The knowledge gained from this rig will be used to design and manufacture an optical access window for the turbine test rig. The current test article is the HPFTP for the SSME, and the configuration to be initially tested is the Alternate TurboPump design (ATD) which Pratt and Whitney manufactured.

TRANSONIC TURBINE RIG
LASER DOPPLER VELOCIMETRY MEASUREMENTS

G.V. Hobson, Associate Professor

Sponsor: Naval Postgraduate School

OBJECTIVE: This proposed work will provided three-component laser Doppler velocimetry (LDV) measurements of transonic flows, as well as total and static pressure distributions, in a annular turbine cascade (ATC) of highly loaded turbine blades. Non-intrusive measurements will be performed with the three-component fibre-optics LDV system. Mean flow and turbulence quantities will be mapped out in detail downstream of the cascade. Three-dimensional viscous flow simulations of the turbine flowfield will also be performed to assess the ability of codes to predict such flows.

SUMMARY: This research project is aimed at obtaining detailed three-dimensional viscous flow measurements in an annular turbine cascade. Three-component LDV measurements have been performed in the corner vortex flow of the Low Speed Cascade. LT. Perretta performed transonic LDV measurements with a one-component LDV system in the Gas Dynamic Laboratory's supersonic blow down wind tunnel. These measurements entailed flowfields surveys across a normal shock in a Mach 1.4 flow, and boundary layer surveys ahead of the shock. Bimodal histograms of the unsteady shock process were measured, and the feasibility of performing backscatter measurements was achieved. A current student LCDR Spitz has performed measuremetns in a Mach 0.8 with the three-component LDV system. These are preliminary before performing two- and thee-component measurements in the ATC.

1992

TURBINE TIP-LEAKAGE FLOWS

G.V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Air Warfare Center (Trenton)

OBJECTIVE: Investigate the nature of turbine tip-leakage flows in the new annular turbine cascade as well as in the Space Shuttle Main Engine High Pressure Fuel Turbo Pump.

SUMMARY: The turbine tip-leakage study will be continued in a newly designed annular turbine cascade facility. The intent for this cascade is to gain experience in taking three-component LDV measurements through a curved window in a highly swirling flow. A stationary tip leakage flow (no relative movement between the tip wall and blades) can be simulated in this facility on a scale typical of small to medium gas turbines. The new three-component fibre-optics LDV has been commissioned and a new three-axis traverse mechanism has also been purchased with NPS OPN funds. This traverse is currently being mounted onto a mobile table so that exploratory three-component measurements can be performed in the corner vortex flow of the Low Speed Cascade. A capability of analyzing 3-D turbomachinery flows now exists at the Department of Aeronautics and Astronautics, with the installation of Rotor Viscous Code Three Dimensional (RVC3D), written by Rod Chima of NASA Lewis Research Center, on the Schools' Supercomputer Workstations.

TRANSONIC TURBINE RIG – LASER DOPPLER VELOCIMETRY MEASUREMENTS

G.V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Postgraduate School, DFR (Merit Proposal)

OBJECTIVE: Establish a continuous running turbine facility for laser Doppler measurements of the intra-blade flows, and establish an experimental database for computer code verification as part of the NASA MSFC Turbine CFD Consortium.

SUMMARY: The SSME turbine has two stages thus the Turbine Test Rig will have to be modified to accommodate the additional stage. Once all the necessary modifications to the rig and the dynamometer coupling has been made the new turbine will be installed and essential performance monitoring probes will be connected. Initial performance tests will be performed to verify these measurements with those made by NASA MSFC in their blowdown facility.

Before these performance tests can be carried out the casing of the turbine will have to be modified to accommodate a laser access optical window. After the performance tests have been completed the LDV mesurements will commence. Initially two-component measurements at mid span of the turbine blades will be performed. Depending on the success of these measurements three-component measurements will be taken.

MEASUREMENT AND COMPUTATION OF TURBOMACHINERY FLOWS

G.V. Hobson, Associate Professor
Department of Aeronautics and Astronautics
Sponsor: Naval Psotgraduate School, DFR (RIP)

OBJECTIVE: Develop an improved design capability for turbomachinery components by conducting an experimental and computational investigation into the viscous flow behavior in such components.

SUMMARY: The experimental investigation of the NASA Controlled-Diffusion Compressor Blades continued with laser sheet flow visualization video recordings of the leading edge separation bubble at 48 degrees inlet flow angle. These results were presented at a seminar at NASA LeRC in May, 1992. The inlet manifold and suction slots on the Low Speed Cascade Tunnel, have been completed and preliminary endwall boundary layer suction was performed with the inlet flow angle at 48 degrees. Initial spanwise pitot-static probe measurements have indicated that the suction slots decrease the endwall boundary layer to approximately half its original thickness. Presently the cascade inlet flow angle has been reduced to 43 degrees and baseline rake probe surveys have been completed upstream of the cascade, with no endwall slots installed. The slots have been modified to include a porous wall behind the slot openings for more even suction in the pitchwise direction. Two-component LDV measurements aare complete at this inlet flow angle to establish a baseline flowfield. The TPL took delivery of all the fibre optics for a three-component LDV system, which is currently being commissioned for 3D endwall measurements in the cascade.