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A FUNDAMENTAL STUDY OF SUCTION FOR LAMINAR FLOW CONTROL (LFC)

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Progress Report for Period November 1991 to October 1992

By Jonathan H. Watmuff

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SUMMARY

This report covers the period forming the first year of the project. The aim is to experimentally investigate the effects of suction as a technique for Laminar Flow Control. Experiments are to be performed which require substantial modifications to be made to the experimental facility. Unfortunately insufficient funds were available to fully complete the fabrication. As a result only slightly more than half of the necessary modifications were completed this year. All the design work has been performed and the drawings are complete. Funding for completion of the fabrication and for some items of equipment next year has been obtained from the Director's Discretionary Fund so the work can now proceed.

Considerable effort has been spent developing new high performance constant temperature hot-wire anemometers for general purpose use in the Fluid Mechanics Laboratory. The design was based on results presented in a series of papers by the author. Twenty instruments have been delivered, at a cost of around \$1k each, and all users report that the performance is as good as, if not better than, commercially available instruments costing \$8k each, while the noise level is considerably less. The process of writing a "User's Guide" is approaching completion.

An important feature of the facility is that it is totally automated under computer control. Unprecedently large quantities of data can be acquired and the results examined using the visualization tools developed specifically for studying the results of numerical simulations on graphics work stations. The experiment must be run for periods of up to a month at a time since the data is collected on a point-by-point basis. Several techniques were implemented to reduce the experimental run-time by a significant factor. Extra probes have been constructed and modifications have been made to the traverse hardware and to the real-time experimental code to enable multiple probes to be used. This will reduce the experimental run-time by the appropriate factor. Hot-wire calibration drift has been a frustrating problem owing to the large range of ambient temperatures experienced in the laboratory. The solution has been to repeat the calibrations at frequent intervals. However the calibration process has consumed up to 40% of the run-time. A new method of correcting the drift is very nearly finalized and when implemented it will also lead to a significant reduction in the experimental run-time.

MODIFICATIONS TO WIND TUNNEL

Leading edge, extension to contraction and side walls

The base flow consists of a laminar boundary layer in a zero pressure gradient. In the original configuration the test plate was attached to the floor of the contraction. The influences of the FPG within the contraction and the APG at the exit on the test plate boundary layer are uncertain. Therefore a 24:1 elliptic leading edge has been built for the purpose of starting a new layer on the test plate. The leading edge is downstream of the APG associated with the contraction exit and it is located in the free-stream. An extension to the contraction floor will combine with the lower surface of the leading edge to form a slot for the removal of the contraction boundary layer. It is anticipated that the slot will function passively i.e. an external fan will not be required. The leading edge and floor extension have been constructed but they have not been tested as a unit at this stage.

New ceiling, spacers for traverse and side-walls

A new plexiglass ceiling for setting the zero pressure gradient has been constructed by the model shop. Spacer blocks will be needed to raise the traverse assembly and the sidewalls to correctly position them relative to the new height of the test surface above the optics table which forms the base of the test section. Minor extensions are also required for the existing side walls in order to complete the test section and these two pieces will be constructed by FML technicians in situ.

Suction surface, plenum chamber and support

Plenum enclosures are required underneath the porous surface for the purpose of maintaining a steady pressure difference for the suction. The porous surface was designed to be as wide as possible to avoid contamination by the boundary layers forming over solid edges. The porous surfaces are also quite thin (e.g. 1mm) so that support must be provided at close intervals. These design objectives require the construction of a large plenum and plate support system to replace the existing solid plate. An important feature incorporated into the new configuration is the ability to interchange various test surfaces.

At the outset, a porous surface was to be used that is typical of those currently being tested on aircraft wings i.e. 0.002" dia. holes spaced on a 0.020" grid. The manufacturer of this laser drilled material is located in the U.K. The quotation of $10,000 for 0.040 inches thick porous titanium turned out to be less than half the cost of other more suitable porous materials that are thicker for example. Drawings were prepared for the suction surface support and plenum chamber assembly. It was recognized that working with such a thin sheet would be difficult and there would be considerable uncertainty with many aspects of the assembly procedure. After consultation with the relevant Ames shops, a small subset of the final assembly has been designed and built for the purpose of testing the adequacy of the scheme. A method was devised for attaching thin suction surfaces to the plenum and support assembly using epoxy resin which maintains a high degree of flatness of the surface.

During the course of the project, Tadjfar and Reda (1991) obtained numerical results which indicated that a pair of counter rotating longitudinal vortices could form in the vicinity of a hole when the suction is strong. This observation is of concern because further downstream, in the region beyond the capabilities of the calculations, these vortices could defeat the purpose of the suction and even lead to an earlier transition. Almost nothing is known about 3D disturbances generated by suction holes despite the potentially negative influence.

On the basis of these findings the objective of the project has been modified to focus more directly on 3D disturbances generated by suction holes. A porous surface has been designed which is geometrically similar to those used in LFC flight tests but the hole size and spacing will be scaled up by a factor of 20, i.e. 1mm (0.040in) diameter holes spaced on a 10mm (0.40in) grid. This scaling will provide enough spatial resolution to detect the formation of disturbances in the vicinity of the holes while still maintaining a surface length-scale to boundary thickness ratio that is representative of flight conditions. About 15,000 holes will be required in the scaled up porous surface. Preliminary tests in the machine shop have demonstrated that it is feasible to drill each hole individually using an NC machine. Added benefits are that the thickness of the surface can be increased to around 0.080" and the difficulties of procurring material from overseas are avoided. All the design work is now complete and the drawings are ready for submission to the machine shop.

ENHANCEMENTS TO EXPERIMENTAL METHODS

Hot-wire calibration drift

Hot-wire calibration drift is a source of great frustration in the laboratory owing to the large range of ambient temperatures. A major reason for not implementing temperature drift correction schemes in the past is that the apparatus is totally automated and this allows calibrations to be performed at frequent intervals. In essence, the solution to the drift problem has been to repeat the measurements until the drift check obtained after the measurements is within a certain percentage (e.g. 1%) of the drift reference obtained immediately following calibration. One negative aspect of this "brute force" approach has been that up to 40% of the total experimental run-time is consumed with calibration procedures. Further, it has been necessary to sift through large quantities of data and there is evidence to suggest that sometimes the wires can drift away from calibration and then back to the calibration just before the check is performed i.e. the scheme is not foolproof.

Platinum and Tungsten are the most commonly used metals for hot-wires. Platinum has a strong resistance to oxidation but its tensile strength is about 1/5 that of Tungsten. While the Tungsten is stronger, it suffers from oxidation at elevated temperatures. A feature available with both Pt-10%Rh and pure Platinum wires is that they can be supplied with a thick silver coating (Wollastan process) and this greatly helps with probe construction i.e. manipulation is easier while soldering onto the prongs. Only the central region of the silver is etched away to provide the sensitive filament which is located away from the prongs. Pt-10%Rh has a tensile strength about 50% that of pure Platinum so it was chosen for use with the facility.

Initial experiments indicated that the drift appeared to be a function of some other variable in addition to temperature. In follow on work the calibration and drift characteristics of five probes were monitored simultaneously. Recently, Platinum coated Tungsten wire has become available which offers the best advantages of each material i.e. the strength of Tungsten combined with the oxidation resistance of Platinum. A 2.5μm diameter sample of this material was obtained for one wire and a regular 5μm Dantec Tungsten wire was used in addition to three 2.5μm Pt-10%Rh wires. The three Pt-10%Rh wires showed considerable scatter when plotted against temperature compared to the other wires. It turns out that Pt-10%Rh has a temperature coefficient of resistivity about half that of pure Platinum and pure Tungsten. Consequently, for a given resistance ratio, the Pt-10%Rh wires would be heated to approximately twice the temperature above ambient than either Tungsten or pure Platinum wires. A plausible explanation for the scatter is that the Pt-10%Rh wires are subject to aeroelastic deflections since the material is much weaker at the higher operating temperature. The calibration changes as the bow in the wire changes slightly. This idea was supported by the much reduced scatter observed when the wires were run at a lower resistance ratio.

The scatter in the drift versus temperature plots that is common to all probes is most likely caused by fluid property variations with changes of atmospheric pressure. Implementation of barometric measurements into the experimental program have been completed and tests will be conducted shortly to see just how long a single calibration remains valid when it is subject to the appropriate correction.

A small bath was constructed for the purpose of electrolytic plating of silver onto the 2.5μm diameter Platinum coated Tungsten wire. The technique is quite simple and enough material for about six probes can be produced in about 30 minutes. All wires will be constructed using this material in the future because it offers all the best features i.e. the strength of Tungsten, the oxidation resistance of Platinum and the convenience of working with a larger diameter wire for attaching to the prongs.

Multiple probes

Benchmark tests indicated that the double-buffered data acquisition/processing scheme for mean flow and Reynolds stresses provides an indefinitely sustainable throughput of 60kHz for a normal wire and 25kHz for a crossed-wire. Since these rates are far in excess of the rates estimated for a single probe in laminar flow control experiments, the higher level code was enhanced to incorporate multiple probes. The use of multiple probes will reduce the total experimental run-time by the corresponding factor e.g. measurements requiring a 30 day continuous run with a single crossed-wire will now take only 5 days if 6 probes are used. Drawings were submitted to the Machine Shop for construction of multiple probe holders needed for the traversing mechanism. Modifications were made to the Dantec probes in the form of a size reduction and stiffening of the prongs and the installation of 2.5 μm diameter thick silver coated, thin Platinum coated Tungsten mentioned above.

NEW FML HOT-WIRE ANEMOMETERS

Over the last few years much effort has been spent on the development of new high performance constant temperature hot-wire anemometers for general purpose use in the Fluid Mechanics Laboratory. The design was based on results presented in a series of papers by the author i.e. Watmuff (1987), Watmuff (1988), Watmuff (1989) and Watmuff (1990a, 1990b). Twenty instruments have been delivered, at a cost of around $1k each, and the performance is equivalent to commercially available instruments costing $8k each, while the noise level is much less.

Considerable time this year was spent on writing the NASA Technical Memorandum "A High-Performance Constant-Temperature Hot-Wire Anemometer". The memorandum has evolved into an extensive publication. The philosophy and ideas behind the design are discussed in detail. The original basis for the design was a 7^{th}-order analysis derived by the author while at Princeton University (see Watmuff 1987). Since that the time the derivation has been "algorithmized" so that the transfer functions can be derived for a system of arbitrary complexity. This work will be published for the first time in the memorandum as well as later in a journal publication. The memorandum will also contain a schematic of the circuit and a parts list with suppliers. Enough information will be provided to enable the anemometer to be constructed by others. In addition the memorandum will act as a "User's Guide". The hot-wire anemometer is a difficult instrument to operate properly and detection of an incorrect mode of operation can be quite subtle. The memorandum will provide examples of incorrect operating modes which draw on the analysis mentioned above for an explanantion. The instructions and the collection of tips should prove valuable to users. A number of researchers outside the FML have already heard of the anemometer and the author has started receiving requests for the memorandum even at this preliminary stage.

Invited talks and seminars

(1) A seminar was given at the California Institute of Technology in November 1991.

(2) A talk was given at University of Melbourne, Australia, in September 1992.

(3) A talk was given at CSIRO, Highett, Australia, in September 1992.

(4) A talk was given at Aeronautical Research Laboratory, Fisherman's Bend, Australia, in September 1992.

PUBLICATIONS

Watmuff, J. H. 1991 "An Experimental Investigation of Boundary Layer Transition in an Adverse Pressure Gradient". Forty-Fourth Annual Meeting of the Division of Fluid Dynamics, American Physical Society, Scottsdale, Arizona, November 24-26, 1991

"Experimental and Numerical Study of a Turbulent Boundary Layer with Pressure Gradients", by Philippe R. Spalart and Jonathan H. Watmuff. Paper accepted for publication in the Journal of Fluid Mechanics.

"A High-Speed Cross-Wire Data-Reduction Algorithm", By Jonathan H. Watmuff. Paper submitted to the Journal of Experimental, Thermal and Fluid Science.

REFERENCES

Tadjfar, M. and Reda, D. C. 1991 "Flow Field Near a Single and a Row of 3D Suction Holes Inside a Laminar Boundary Layer". Forty-Fourth Annual Meeting of the Division of Fluid Dynamics, American Physical Society, Scottsdale, Arizona, November 24-26, 1991

Watmuff, J.H. 1987 " Higher Order Effects in the Frequency Response of the Constant temperature Hot-wire Anemometer". ASME Applied Mechanics, Bioengineering and Fluid Mechanics Conference, Cincinnati, Ohio, June 1987.

Watmuff, J.H. " Increasing the Frequency Response of Constant Temperature Hot-wire Anemometer Systems for use in Supersonic Flow". Presented at AIAA 26th Aerospace Sciences meeting, Reno, Nevada, January, 1988.

Watmuff, J.H. " The effects of Feedback Amplifier Characteristics on Constant Temperature Hot-wire Anemometer Systems". Presented at the tenth Australasian Fluid Mechanics Conference, Melbourne, Australia, December, 1989.

Watmuff, J.H. " Tuning the Constant-Temperature Hot-Wire Anemometer". Presented at the ASME Symposium on Heuristics of Thermal Anemometry, Ontario, Canada, June 1990.

Watmuff, J.H. " Frequency response of hot-wire anemometers". NASA Tech Brief ARC-12469, 1990.