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STUDIES OF THE DYNAMIC STALL OR
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FINAL REPORT

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BY

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INTRODUCTION

The study described here is aimed at the understanding of unsteady flows over lifting surfaces and in particular of the dynamic stall of helicopter rotors. It has been carried out in part in the IIT oscillating flow wind tunnel and in part by observations of flow patterns made visible by hydrogen bubbles in a small water tunnel.

The flow relative to an airfoil profile at a given radial location on a rotor blade of a helicopter in forward flight can be modeled with some success by a two-dimensional sinusoidally oscillating airstream over an airfoil oscillating 180° out of phase in pitch.

While oscillating airfoils in purely steady flows have been studied extensively (1) not much attention has been paid to the other component of the above model, i.e. the effect of the oscillations of the velocity of the airstream relative to the airfoil due to the conbination of the rotary motion of the blade and the forward flight of the helicopter.

In the first phase of the IIT investigation detailed studies were made of the general characteristics of oscillating flows over a stationary airfoil and of the effects of frequency, amplitude and Reynolds Number upon them. The second phase of the study was focused on the flow model simulating the helicopter rotor environment by combining the oscillations of the free stream with the oscillations in pitch of the airfoil. This required structural modifications of the test section of the wind tunnel and the addition of a crank mechanism to oscillate the airfoil and of an automatic means for maintaining the frequencies of the two oscillations and the proper phase relationship between them.

The entire investigation has been documented in detail in a series of M.S. and Ph.D. theses and presented in a number of technical papers. These publications, listed in the BIBLIOGRAPHY contain descriptions of the experimental facilities, of the means employed for the acquisition and processing of data and the results of the experiments and their discussion. They are briefly documented in this final report.

EXPERIMENTAL FACILITIES

(a) Wind Tunnel

The oscillating flow wind tunnel used in this study was built originally for the study of boundary layers in oscillating flows and has been described in detail by Miller and Fejer (2). It has a 2 ft x 2 ft test section and houses at the downstream end of the test section a set of rotating shutter blades mounted on horizontal shafts for the generation of velocity oscillations in the wind tunnel circuit. The shutter is driven by a DC motor through a gear box of adjustable speed ratio.

Fluctuations in amplitude up to 40% of the mean velocity are attainable at frequencies ranging from 1 to 60 Hz at velocities up to 100 ft/sec. The changes in mean velocity are produced by a slip clutch located between the a.c. motor and the pulley driving the wind tunnel fan.

The periodic changes in angle of attack are accomplished by a mechanism devised by Hajek (3) consisting of a counterweight equipped crank, a connecting rod and an actuating lever which is attached to one of the ends of the shaft supporting the airfoil. The relative positions and lengths of these components are adjustable providing a range of amplitudes of the angle of attack up to ±20° and mean angle settings from 0° to 20°. The crank mechanism is driven by a printed circuit DC motor. Coupling of the motion of the airfoil with the oscillations of the free stream are accomplished electronically through a phase locking circuit which controls the amplifier powering the DC motor. The signals actuating the circuitry are provided by two magnetic pickups, one located on one of the shutter vanes and the other on the crank of the mechanism oscillating the airfoil.

(b) 2" x 8" Water Funnel For Flow Visualization

The water tunnel used as an aid in interpreting the quantitative wind tunnel data is a small recirculating water loop consisting basically of two cylindrical reservoirs of 18" diameter connected by a 12" long test section of 2" width and 8" height with Plexiglas walls. 3" daimeter piping connecting the reservoirs throttle valve and a circulating pump complete the loop. Operation in the oscillating mode is accomplished by means of an 18" diameter reciprocating piston acting on the surface of the downstream reservoir. The details of the tunnel and of the hydrogen bubble visualization technique that was developed by G. Ruiter with the quidance of H. M. Nagib and utilized in this study is described in Ref. 4. Modifications for the purposes of this study were made by J. Zolan.

(c) Instrumentation and Data Acquisition

A hollow airfoil of 30 cm chord made of aluminum, having an NACA 0012 profile, designed by Hajek was utilized in this study. It was equipped with 18 static pressure orifices connected through a remotely controlled Scanivalve pressure switch with a pressure transducer located inside of the airfoil. The static pressure data were supplemented by velocity measurements by means of a constant temperature hot-wire anemometer. Part of the investigations were made using boundary layer trips at the leading edge of the airfoil in order to increase the effective Reynolds Number of the tests.

The outputs of the pressure transducer and hot-wire were converted into instantaneous pressures and velocities by means of periodic sampling and averaging techniques and the educted signals were used to compute ensemble averaged "instantaneous" chordwise pressure distributions. In the case of the stationary airfoil instantaneous boundary layer and wake velocity profiles were also acquired at various chordwise locations. The conception of the data acquisition system is due to Dr. H. Fujita, post doctoral research fellow at IIT from Sept. 1973 to Aug. 1975. Credit for the realization of the major portion of the signal processing system and for its calibration is due to L. S. Saxena. Contributions were also made in this area by D. N. Katariya, T. Hajek and B. Hsieh.

RESULTS

As mentioned earlier the study consisted of two phases. The airfoil was stationary in the first phase and oscillating in the second, with the flow oscillating in both cases. Measurements were also made in steady flow with the airfoil at rest and with it oscillating for purposes of comparison with existing data.

(a) Stationary Airfoil in Oscillating flow

This part of the investigation was conducted by S. L. Saxena and his work is documented in detail in his Ph.D. Thesis "An Experimental Investigation of Oscillating Flows Over an Airfoil," May 1977. Visual studies of the flows were carried out by J. Zolan. They are described in his M.S. Thesis "Dynamic Stall on Airfoils in Oscillating Flow," June, 1976.

Saxena focused his study on flows at angles of attack close to the angle of static stall and moderate amplitudes of oscillation (±18%). He found that at this amplitude the oscillations of the free stream had no effect on the angle of stall of the NACA 0012 airfoil.

He discovered that at the low reduced frequency of $K = 0.18$ (corresponding to a frequency of 2.2 Hz) and at a chord Reynolds Number of about 200,000 the flow over the airfoil is globally quasi steady and above the angle of stall, i.e. with the pressure coefficient C_p based on the instantaneous free stream velocity the chordwise distribution of C_p was practically the same as in steady flow. The departure of the average value of the normal force coefficient from the steady flow value was less than 3% and it's instantaneous value exhibited a maximum deviation of 13%.

At a much higher frequency K = 0.9 (9.7 Hz) the unsteady effects were somewhat more pronounced below the angle of stall. The departure of the average normal force coefficient and the maximum deviation of its instantaneous value from the steady flow values increased to 6% and 17% respectively but the shape of the pressure distribution revealed that the flow could be again considered quasi steady. But above the angle of stall the structure of the separated flow was drastically altered by the unsteady part of the local pressure gradients that are greatly augmented with an increase in frequency. This resulted in a 60% increase of the average normal force coefficient from its steady flow value with the instantaneous value of this increase fluctuating between 26% and 83%.

It was found that when the oscillating flows were quasi steady they contained a laminar separation bubble near the leading edge just as in steady flows and that the size and location of this bubble and the thickness of the boundary layer were being modulated in phase with the oscillations of the free stream. And when the bubble was eliminated by placing a row of boundary layer trips on the leading edge of the airfoil the normal force coefficient in the tripped and untripped flow were found to be about the same. It can be concluded from this that at least for the range of parameters used in these tests oscillating flows below the critical angle are essentially Reynolds number independent. This is an important finding since the range of Reynolds Number values in these tests is significantly lower than on full scale helicopter rotors. The visual observations made by Zolan in the small water tunnel confirmed the existance of a "quasi steady" regime at low reduced frequencies in which the fluctuations did not destroy the potential character of steady flow even at the larger amplitudes of fluctuations. But for certain combinations of threshold values of amplitude and frequency the flow separated during the decelerating part of the cycle at all angles of attack of the airfoil. The separation originated near the trailing edge and extended usually over the entire upper surface. When the angle of attack was small separation occured also on the lower surface. The separated regions contained an energetic layer of reversed flow which appeared to generate by interaction with the free stream one or more larger size vortices that moved downstream as the flow accelerated.

(b) Oscillating Airfoil in Oscillating Flows

The transition from the stationary airfoil experiments representing the first phase of the study to the oscillating airfoil experiments of the second phase was carried out by T. Hajek. It consisted of the modifications of the wind tunnel and accessories that has been described in the section "Experimental Facilities" and of a series of tests for comparison of the oscillating flows over oscillating airfoils with steady flows over oscillating airfoils and oscillating flows over stationary airfoils. The study is presented in detail in the M.S. thesis of Mr. Hajek "Oscillating Airfoils in Unsteady Flows" which has been completed recently.

In Hajek's tests the NACA 0012 airfoil was oscillating around it's quarter chord point about a mean angle of 10° with an amplitude of ±6° in a free stream having a mean velocity of 8.4 m/sec and oscillating with an amplitude of ±2.4 m/sec. The oscillations of the flow had the same reduced frequency K = 0.224 (2.7 Hz) and were 180° out of phase.

Hajek found that by introducing an oscillation of the free stream velocity into the steady flow around an oscillating airfoil the latter may be strongly affected, e.g. lose its quasi steady character. In steady flow an airfoil set at an angle of attack of 10° and oscillating with an amplitude of ±6° has been shown to be quasi steady (Ref. 5). When an oscillation of the mean velocity of an amplitude of ±29% was superimposed the flow lost its quasi steady character completely, with the chordwise pressure distributions in the accelerating part of the cycle differing radically from those in the decelerating part. As a consequence of these differences there appears a hysteresis loop in the plot of the normal force coefficient vs. instantaneous angle of attack. The presence of a hysteresis loop in the lift curve is a well known feature of dynamic stall of airfoils and has been studied in great detail in steady flows. However Hajek has found that the quasi steady unstalled flow around an oscillating airfoil in steady flow may change into a flow displaying the characteristics of dynamic stall when oscillations in free stream velocity are added. Predictions of the dynamic performance of rotor blade profiles in forward flight based on experimental results obtained in steady flows must therefore be suspect of being erroneous.

The final part of this investigation has been carried out by B. J. Hsieh and is being documented in his Ph.D. Thesis, which is at this time available only in draft form. The estimated completion date of the thesis in its final form is April 1. The title of the thesis is "Dynamic Stall in Oscillating Flows."

Hsieh investigated the NACA 0012 airfoil set at a mean angle of attack of 15° and oscillating ±10°. When the oscillation occurs in steady flow the airfoil is in dynamic stall. In this study Hsieh observed this oscillation both in steady flow and oscillating flow and with and without boundary layer trips. The tests were made at two sets of frequency and amplitude, 2 Hz, 18% and 3.5 Hz, 24%. Instantaneous (educted) static pressure distributions averaged over 10 or more cycles revealed,under all conditions, cyclic normal force and moment changes with hysteresis that are typically found in dynamic stall at the higher frequency. The curves of normal force coefficients and moment coefficients vs. instantaneous angle of attack were practically the same when the free stream was steady and when it was oscillating. However, at the lower frequency noticeable differences were found indicative of the interaction between the two oscillations. The same observations were made when the airfoil was equipped with boundary layer trips indicating again the Reynolds Number independence of the phenomena dominating dynamic stall.

CONCLUSIONS

(1) At the low reduced frequencies typically encountered on helicopter rotors in forward flight the flow over a stationary airfoil is quasi steady below and above angles of static stall for amplitudes of the free stream oscillations that are relatively small (18%).

(2) When amplitude and frequency of the free stream oscillation exceed certain threshold values the flow separates at all angles of attack (including 0°) during the decelerating part of the cycle. Separation appears to start at the trailing edge and the separated region contains an energetic layer of reversed flow. At the end of the deceleration one or more vortices appear at the edge of the shear layer between the separated region and the free stream, and as the flow reaccelerates they move into the free stream and are swept downstream.

(3) In the presence of free stream oscillations the same kind of abrupt, leading edge separation occurs at a critical angle on a stationary airfoil as in steady flow.

(4) The unstalled flow over an airfoil oscillating in unsteady flow may undergo dynamic stall when oscillations of the free stream are superimposed on the steady flow.

(5) The features of the flow over an oscillating airfoil in dynamic stall in a steady flow may undergo salient changes when oscillations of the free stream are added.

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This work was carried out in part in collaboration with Professor M. V. Morkovin, who was co-advisor of L. S. Saxena, and benefitted greatly from the interest and assistance provided by Professors H. M. Nagib and J. L. Way. Their helpful ccoperation is greatfully acknowledged.

LIST OF REFERENCES

(1) McCroskey, William J., "Some Current Research in Unsteady Fluid Dynamics - The 1976 Freeman Scholar Lecture," Journal of Fluids Engineering, Trans. ASME Vol. 99, March 1977.

(2) Miller, J. A. and Fejer, A. A., "Transition Phenomena in Oscillating Boundary Layer Flows," J. Fluid Mechanics, Vol. 18, 1964.

(3) Hajek, T. J., "Oscillating Airfoils in Unsteady Flows" M.S. Thesis, IIT, May 1979.

(4) Ruiter, G. H., "Unsteady Flows Over Airfoils," M.S. Thesis, IIT, December 1972.

(5) Carr, L. W., McAlister, K. W. and McCroskey, W. J., "Analysis of Dynamic Stall Based on Oscillating Flow Experiments," NASA TN D-8382, 1977.

BIBLIOGRAPHY

Fejer, A. A., Ruiter, G. H., and Nagib, H. M., "Visualization of Unsteady Flows Over Airfoils," Proceedings of the 2nd Symposium on Turbulence Measurements in Liquids, University of Missouri, Rolla, 1971.

Fejer, A. A., Ruiter, G. H. and Nagib, H. M., "Unsteady Boundary Layer Separation Over Oscillating Airfoils," AFOSR Scientific Report TR-72-0076, Sept. 1971.

Ruiter, G. H., "Unsteady Flows Over Airfoils," M.S. Thesis, IIT, December 1972.

Fejer, A. A., "Flow Visualization Techniques for the Study of the Aerodynamics of Bluff Bodies and of Unsteady Flows," International Congress on Instrumentation in Aerospace Facilities," Record ICIASF-IEEE 1973.

Fejer, A. A. and Fujita, H., "Studies of Dynamic Stall of Airfoils for Helicopter Rotors," Proceedings, Conference on Helicopter and V/STOL Aircraft Research, Ames Research Center, Moffett Field, October 1974.

Katariya, D. N., "Pressure Measurements in Unsteady Flows," M.S. Thesis, IIT, May 1975.

Fejer, A. A. and Morkovin, M. V., "Periodic Flow in Wind Tunnels Produced by Rotating Shutters," Discussion of paper by Charnay and Mathieu, Journal of Fluids Engineering, Trans. ASME, June 1976.

Zolan, J. J., "Dynamic Stall of Airfoils in Oscillating Flows," M.S. Thesis, IIT, June 1976.

Saxena, L. S., "An Experimental Investigation of Oscillating Flows Over an Airfoil," Ph.D. Thesis, IIT, June 1977.

Fejer, A. A., Ruiter, G. H., Zolan, J. J. and Nagib, H. M., "A Study of the Structure of Unsteady Flows over Airfoils," Proceedings, VI Canadian Congress of Applied Mechanics, Vancouver, Sept. 1977.

Saxena, L. S. Fejer, A. A. and Morkovin, "Features of Unsteady Flows over Airfoils," Abstracts, AGARD Symposium on Unsteady Aerodynamics, Ottawa, Sept. 1977.

Guelfi, C. H., "Studies of the Design of a Water Tunnel and of Flows around Oscillating Airfoils," M.S. Thesis, IIT, Dec., 1977.

Fejer, A. A. and Hajek, T. J., "A New Approach to the Study of Dynamic Stall," Proceedings, Fourth European Rotocraft and Powered Lift Aircraft Forum; Stresa, Italy, Sept. 1978.

Saxena, L. S., Fejer, A. A. and Morkovin, M. V., "Effects of Periodic Changes in Free Stream Velocity on Flows Over Airfoils Near Static Stall," Nonsteady Aerodynamics, Editors D.E. Crow and J. A. Miller, ASME, New York, Dec. 1978.

Hajek, T. J., "Oscillating Airfoils in Unsteady Flows," M.S. Thesis, IIT, June 1979 (Final Draft completed)

Hsieh, B. J., "Dynamic Stall in Oscillating Flows," Ph.D. Thesis, IIT, June 1979 (in preparation).

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The interaction of oscillations of the mean velocity of the relative flow with the periodic changes in angle of attack that are produced in the forward flight of helicopters on the airfoil profiles of the rotors has been investigated for the first time. The study conducted in the IIT 2 ft x 2 ft oscillating flow wind tunnel coupled with visual observations in a small water tunnel has revealed that the aerodynamic characteristics of (cont)

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oscillating flows in steady flow, documented by a number of investigators, may be altered significantly when oscillations of the flow velocity are superimposed on those of the angle of attack of the airfoil.

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