1992

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M.S.Chandrasekhara, L.W.Carr, and J.A.Ekaterinaris, "Interferometry and Computational Studies of an Oscillating Airfoil Compressible Dynamic Stall", Proc. of the 5th Asian Congress of Fluid Mechanics, Taejon City, Korea, Aug. 1992, Vol. II, pp.

THE FIFTH ASIAN CONGRESS OF FLUID MECHANICS
August 10-14, 1992 Taejon Korea

INTERFEROMETRY AND COMPUTATIONAL STUDIES OF AN OSCILLATING AIRFOIL COMPRESSIBLE DYNAMIC STALL FLOW FIELD

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ABSTRACT A unique comparison has been made between real time interferograms and full Navier-Stokes computations of the density field over an oscillating airfoil undergoing dynamic stall for compressible flow conditions. Good agreement was found until a dynamic stall vortex formed in the flow. Subsequent evolution of the flow field was found to be very different in the computations. The reasons for this difference have been explained in terms of the leading edge region flow physics and the refined flow modelling that needs to be used for the post-stall flow field.

1. Introduction

The phenomenon of dynamic stall and in particular, the effects of compressibility on dynamic stall are of great importance and interest in the aerodynamics of the retreating blade of a helicopter and of fixed wing aircraft performing maneuvers. The phenomenon relates to production of additional lift beyond the static stall angle by rapidly pitching an airfoil. As much as twice the normal lift can be generated till angles of attack greater than 25 degrees, depending upon the flow conditions. A characteristic feature of the flow is the formation of a large dynamic stall vortex which is primarily responsible for the increase in lift. However, its convection over the airfoil upper surface causes strong pitching moment variation, which could be detrimental to both the aircraft and the pilot. Also, the duration of the naturally occuring delay of stall is short and thus, the benefits of dynamic stall have largely remained unexploited.

Of more fundamental interest is the fact that the phenomenon is a case of forced unsteady separated flow, encompassing significant flow physics ranging from flow separation in unsteady flows, formation of dynamic stall vortex, possible transition of the leading edge boundary/shear layer in the vicinity of vortex formation, extremely large fluid accelerations and immediate deceleration (as the gradients of the pressure coefficients could be ($O(1000)$). It is to be noted that even though the local flow is separated, the overall flow is still attached. Hence, there is reattchment physics also involved. Furthermore, the large leading edge pressure gradients could cause the flow velocities to exceed the sonic velocity even at the low forward speed of M = 0.2. In fact, for certain flow conditions, multiple shocks form over the airfoil [1], whose origin still remains to be properly understood. The subsequent flow development is dramatically affected by these shocks. Such a complicated flow deserves a careful study and the results to be presented are the first steps in this regard. The research consists of two major parts: (1) Experiments and (2) Computations. Both are being carried out at the Navy-NASA Joint Institute of Aeronautics at the NASA Ames Research Center. A description of the experimental facility and technique is followed by a discussion of the computational studies and the two are compared in what is believed to be the first study of its kind.

2. Experimental Facility and Technique

The experiments were carried out in the Compressible Dynamic Stall Facility (CDSF) in the Fluid Mechanics Laboratory of NASA ARC. The CDSF is an indraft wind tunnel with a 25cm. X 35cm. test section and is equipped with two interchangeable drives to produce a sinusoidal variation of the airfoil angle of attack or a rapid ramp-type change of the angle of attack. The flow in the tunnel is controlled by a choked, variable area throat, downstream over a Mach number range of $0 \leq M \leq 0.5$. The flow is produced by a 6MW, $108m^3/s$, continuous running evacuation compressor. This paper pertains to the flow over an oscillating airfoil. The airfoil mean angle of attack, α, can be set to $0 \leq \alpha \leq 15^0$, the amplitude of oscillation, α_m, to $2^0 \leq \alpha_m \leq 10^0$, and the oscillation frequency, f, to $0 \leq f \leq 100Hz$. The uniqueness of the CDSF is that a 7.62cm chord airfoil is supported between two 15cm. diameter optical glass windows by pins that are smaller than the local airfoil thickness. This permits optical access to the airfoil surface everywhere, for flow exploration using nonintrusive diagnostic techniques. Additional details could be found in Ref. [2].

The experimental technique used was the recently developed real time interferometry known as *Point Diffraction Interferometry.* It uses a laser light source, with the beam expanded to 15cm to fill the entire field of view in the standard Z-type schlieren configuration, with the optics aligned to minimize astigmatism. A specially predeveloped, partially transmitting photographic plate replaces the knife edge and some imaging optics are set up further downstream along the beam path. In operation, a pin hole is created *in situ* in the photographic plate with no flow in the test section. This acts as a point diffractor for the reference beam. Light deflected by the flow density changes (signal beam) focusses to a slightly different spot, which will interfere with the light passing through the test section (and thus becomes the reference beam) to produce real time interference images, which are captured on Polaroid film.

The experimental conditions for the present study were: M = 0.3, k = $\frac{\pi f c}{U_\infty}$ = 0.1, (U_∞= free stream velocity) and $\alpha = 10^0 + 10^0 \sin \omega t$.

3. Computational Studies

The flow field was computed using the thin layer Navier-Stokes equation written in the conservation law form for an inertial frame of reference. Second order finite differencing was used for all terms with a Beam-Warming implicit, approximate, iterative factorization scheme being used for space integration and a trapezoidal rule for time integration. All computations were fully laminar. The dissipation coefficients were kept small to minimize the alteration of the original partial differential equations. The boundary conditions were the no-slip condition for the velocities at the airfoil surface and the density and pressure were obtained from the interior by simple extrapolation. At the outer boundaries, zero order Riemann invariant extrapolation was used. The computational grid was of the C-type.

The computed density field was converted into 'interference fringes' corresponding to the density resolution obtained in the experiment using image processing. This involved analyzing the experimental data for the particular Mach number and creating a similar interferogram for the computational flow field at identical conditions on an IRIS Workstation. Subsequently, the experimental interferogram was digitized and the two images were displayed as shown in Fig. 1 and 2.

4. Results and Discussion

In Fig. 1, the result from the two studies are compared for the pre-stall angle of attack of 10 degrees. A first look will reveal that the fringe patterns are quite simliar and that the agreement is good. A counting of the fringes shows this to be the case on the lower surface of the airfoil. However, on the upper surface, more fringes could be seen in the experiment than in the computations. Yet a numerical comparison of the density (and Mach number) field shows that the results are within 5% of each other. Since interferometry is a spanwise averaging technique, this agreement with the computed central plane of the airfoil flow should be considered good.

In Fig. 2, a comparison is shown at the post-stall angle of 17 degrees. (The static stall angle at this Reynolds number is 12.4^0 and the dynamic stall angle at k = 0.1 is 18.1^0). Whereas the attached flow on the underside still agrees well with the computations, the separated flow in the computed field is significantly different. For example, two discrete vortices could be seen in it, but in the experiment, only a single vortical structure, connected to the leading edge shear layer could be seen. Still, the vertical extent of the flow is nearly the same in both cases. Reasonable agreement with the overall measured forces and moment distributions were obtained in the computations [3]. Yet, a distinctly different flow structure is present. This is because, the force and moment coefficients are integrated quantities, which are not very sensitive to the details of the flow structure. It is believed that these differences originate primarily from the physical modelling of the critical leading edge flow field. As stated earlier, the leading edge shear layer is very thin (and hence needs many more grid points), will undergo transition over a finite length. The present day calculations are either fully laminar or turbulent or in some cases, a combination with an arbitrarily fixed transition point. None of the current methods accounts for the transition length, growth of the instabilities, formation of a separation bubble and offer a proper turbulent model (see Ref. [4]). In addition, there is the physics associated with the local supersonic flow. All these have an overwhelming influence on the evolution of the flow as obtained from the computations.

5. Conclusions

The dynamic stall flow field over an oscillating airfoil as seen from experiments has been compared with that obtained from computations. Good agreement can be found when the flow was still attached. However, in the post-stall stage of the flow, large differences are seen. A plausible explanation is offered for such differences and it is believed that when the various physical aspects of the leading edge flow are properly included in the modelling, the numerical studies will contribute better to the understanding of this immensely complex flow field.

References

[1] Chandrasekhara, M.S., Ahmed, S., and Carr, L.W., Schlieren Studies of Compressibility Effects on Dynamic Stall of Airfoils in Transient Pitching Motion, AIAA Paper No. 90-3038.

[2] Carr, L.W., and M.S.Chandrasekhara, Design and Development of a Compressible Dynamic Stall Facility AIAA Paper No. 89-0647.

[3] Carr, L.W., Platzer, M.F., Chandrasekhara, M.S., and Ekaterinaris, J.A., Experimental and Computational Studies of Dynamic Stall, Proc. 4^{th} Symposium on Numerical and Physical Aspects of Aerodynamic Flows, Chapter 14, pp. 239-256, Springer-Verlag, 1990.

[4] Clarkson, J.D., Ekaterinaris, J.A., and Platzer, M.F., Computational Investigation of Airfoil Stall Flutter Proc. 6^{th} Intl. Symp. on Unsteady Aerodynamics, Aeroacoustics and Aeroelasticity of Turbomachines and Propellors, Un. of Notre Dame, Sep. 15-19, 1991.

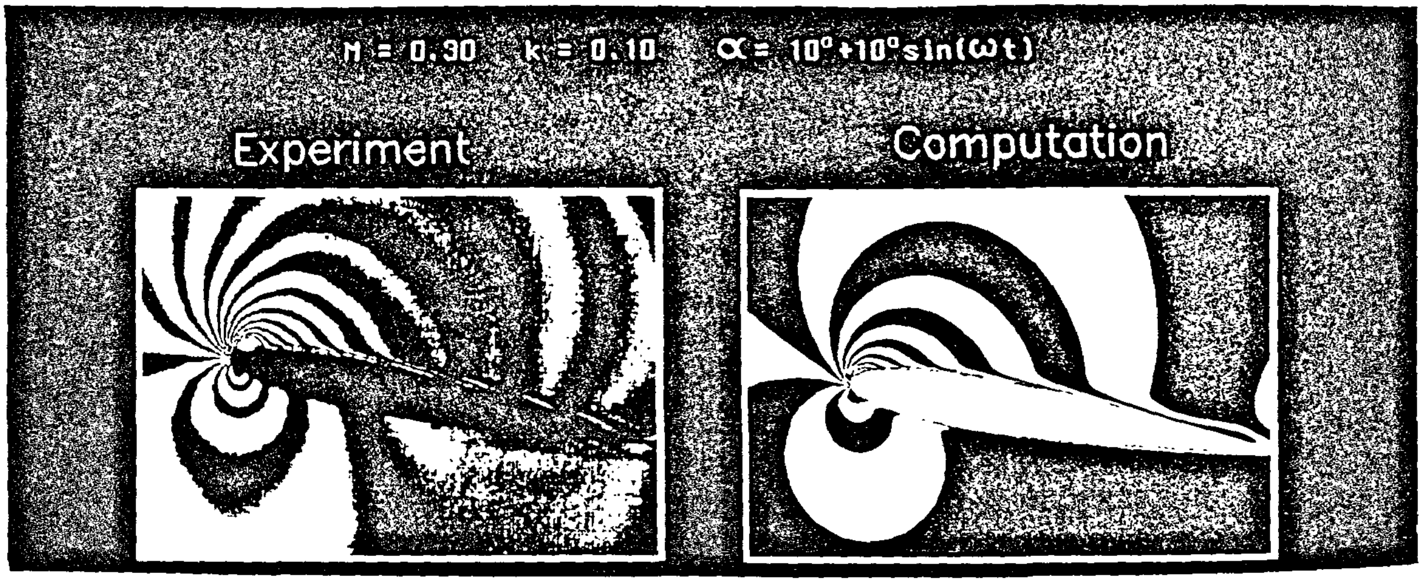

Fig. 1. Comparison of the Pre-Stall Flow Field, $\alpha = 10^0$.

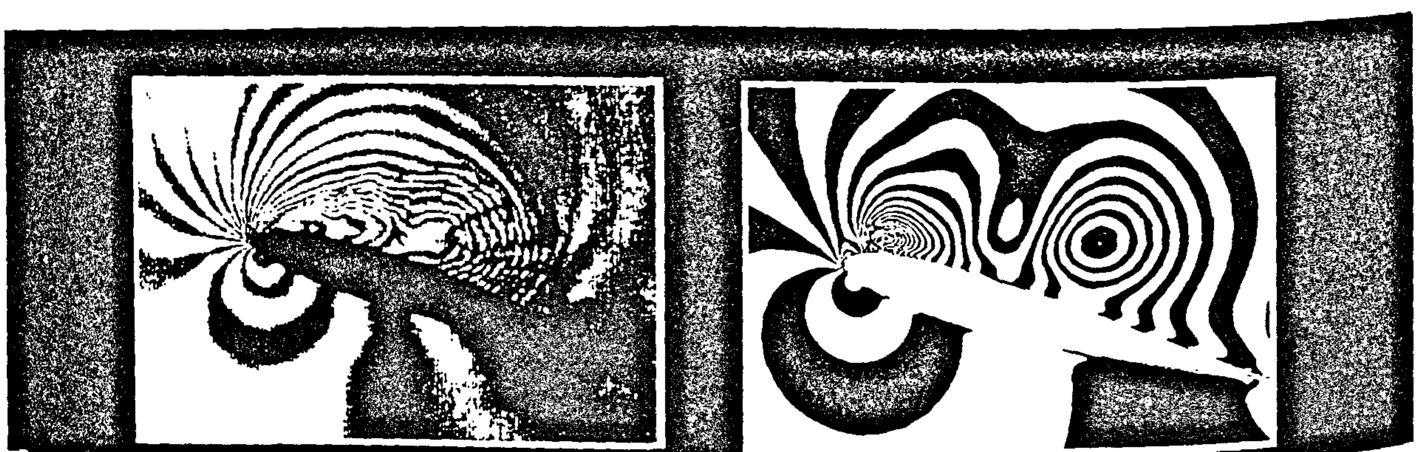

Fig. 2. Comparison of the Post-Stall Flow Field, $\alpha = 17^0$.

PROCEEDINGS
OF
THE FIFTH ASIAN CONGRESS
OF
FLUID MECHANICS

August 10-14, 1992
Taejon, Korea

Editors : K.-S. Chang and D. H. Choi

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