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Investigation of dynamic stall onset

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Abstract

In a 2003 test campaign in the DLR-VAG test stand unsteady pressure distributions during dynamic stall have been measured on a 2D-wing model with OA312 airfoil section. To investigate the effect of transition on dynamic stall onset different tripping devices have been fixed at the leading edge of the model. Adhesive tapes of different thickness as well as corundum with various grains have been used as tripping material. In addition to the experiments numerical calculations have been carried out based on the solution of the unsteady 2D-RANS-equations including a turbulence and transition model. In the present investigation it is shown that different physical flow phenomena can be identified which are triggering the onset procedure of dynamic stall. Three different flow-scenarios have been studied in detail: (1) Free transition during dynamic stall, ($M = 0.2$). (2) Fully turbulent flow, ($M = 0.2$). (3) Flow at $M = 0.4$, compressibility effects. Unsteady measured and calculated pressures have been compared for these cases and good agreement has been found. The calculations then are used for detailed flow investigations including the development of leading edge separation bubbles as well as trailing edge separation areas.

Keywords: Dynamic stall; Unsteady separated flow; Transition; Stall onset; Separation bubble

1. Introduction

Dynamic stall is a very complex flow phenomenon occurring on helicopter rotor blades as well as on wind energy converter and, known as rotating stall also on blades of turbo machinery. In all cases dynamic stall is a limiting factor as high speed and maneuver flight capabilities of helicopters as well as limited power production of wind turbines are concerned.

Although numerous studies have been published recently on the subject [3,4] the details of dynamic stall flow characteristics are not as yet fully understood. However if means to favorably control dynamic stall are envisaged [7,8,12] a completion of the knowledge base for the phenomenon is of crucial importance. In [8] it has already been shown that the flow around the leading edge of the oscillating airfoil plays a key role in the development and shedding of a concentrated vortex known as the dynamic stall vortex. The favorable effect of this vortex is the increase of lift during part of the cycle. However, shedding of the vortex into the wake causes very large excursions in drag and pitching moment, which are undesirable effects.

In the present paper both experimental as well as numerical investigations have been used to study the complex flow during dynamic stall and in particular during dynamic stall onset. During the phase of dynamic stall onset the concentrated vortex starts to develop and short time later lifts off the upper surface of the blade. This procedure is influenced by different flow phenomena: In a low Reynolds number flow transition from laminar to turbulent plays an important part in the development of the flow close to the airfoil leading edge [4,6,16]. One or more separation bubbles may develop and transition takes place over these bubbles. At high Reynolds number flows which are closer to full size reality a separation bubble is avoided completely. In the present tests this has been accomplished by appropriate tripping devices fixed to the airfoil leading edge. If the Mach number of the flow is increased from $M = 0.2$ to $M = 0.4$ the effects of compressibility occur: Now a supersonic bubble develops over part of the cycle which is terminated by a single strong shock wave or by a shock wave system [3]. Shock induced separation may occur and influence dynamic stall onset.

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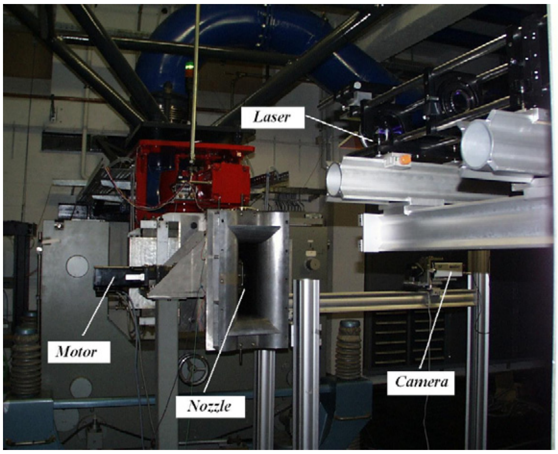

Fig. 1. Wind tunnel test set-up.

2. Test set-up

The DLR-VAG test facility, which is suitable for dynamic stall investigations, has been described already in [11]. Fig. 1 shows the main elements of this test facility: The nozzle of the blow down wind tunnel, the stepping motor to oscillate the model and the test set-up for PIV measurements carried out in a separate test campaign [11].

Dimensions of the test section are: Height $H = 0.35$ m, span $S = 0.1$ m, model chord $c = 0.1$ m, airfoil section OA312. The model is driven in sinusoidal mode by a stepper motor realizing frequencies up to 20 Hz. In the present stage a Mach number variation from low speed to $M = 0.4$ could be realized.

The present model was equipped with six pressure transducers (Kulites type XCQ-062-1 bar-A), the six pressures have been measured simultaneously for 5324.7 ms total measuring time. A sampling rate of 10 kHz has been used for all test points.

Fig. 2 shows first of all steady pressure distributions at two different incidences as calculated and measured. A best fit between calculation and experiment is achieved, if the incidence for the calculation is increased by one degree. It is assumed that the lift increase in the experiment is caused by wind tunnel wall interference effects. A simple correction has therefore been applied also for the unsteady data: The nominal incidences of the measurements have also been increased by one degree.

3. Numerical method

The numerical method used in the present study has frequently been applied for dynamic stall investigations [13]. The RANS-code is based on the approximate factorization implicit methodology originally developed by Beam and Warming [1]. Special emphasis was placed to resolve the time dependencies of the flow to a high degree. As much as 10^5 time steps per cycle have been used throughout ($\Delta T = 2\pi/(\omega^* \times 10^5)$). About 2–3 cycles were sufficient to obtain a time periodic solution. A C-grid topology with deforming grid lines during oscillation was used with 385×81 grid points. Values of $y+ \sim 1$ have been realized through out, about 35 grid points represent the boundary layer.

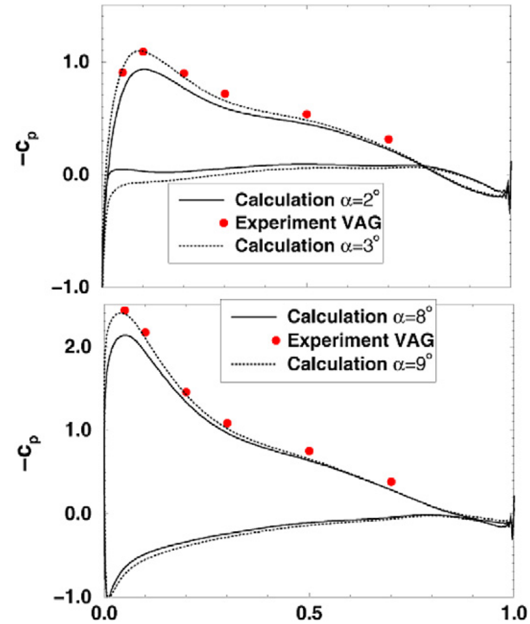

Fig. 2. Steady results: $\alpha = 2°$ (upper), $\alpha = 8°$ (lower).

Experience with this code has shown that for dynamic stall calculations the one-equation Spalart–Allmaras turbulence model [14] yielded the most accurate results. This model has therefore been used in the present study. For the investigation of free transition a suitable transition model is inevitable. It has been shown before that a model based on Michel's criterion for the determination of transition onset together with an exponential growth model to characterize the transition zone [5,7], gives quite accurate results even in the case of deep dynamic stall [10]. To define the edge of the boundary layer the function

$$F = y_n / c^* \Omega$$

plays the key role, with: $y_n =$ normal distance from surface, $c =$ airfoil chord, $\Omega =$ total vorticity.

Marching outwards from the maximum of this function, F_{max}, the boundary layer edge δ is defined at the position, where the function F has been decayed to 50% of F_{max}. From this information the necessary boundary layer quantities like δ_1, δ_2 and U_e (displacement and momentum loss thickness, velocity at the outer edge of the boundary layer) are determined. This model has simply been applied in a quasi-steady mode, i.e., for each time-step separately.

4. Unsteady results

In the present investigation deep dynamic stall with $\alpha_0 = 10°$ mean incidence and $a_1 \approx 10°$ amplitude has been investigated.

Three different cases have been studied in detail:

(1) Free transition at $M = 0.2$.
(2) Fully turbulent flow at $M = 0.2$.
(3) Free transition at $M = 0.4$.

Experiences with the present code did not show a problem with Mach numbers even as low as $M = 0.1$.