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AN AERODYNAMIC ANALYSIS OF THE 3D FLOW AROUND THE SSC-A09 AIRFOIL

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Abstract

Studies on the 3D flow around a section of a rotor blade based on the SSC-A09 airfoil were presented. An investigation has been performed using experimental and computational tools. The research was conducted for a wide range of angles of attack and at several velocities. The most interesting part of an analysis concerned on unsteady flow conditions corresponding to stall.

***Keywords**: 3D flow, CFD, wind tunnel test, oil visualisation*

1 Introduction

In the case of forward flight of a helicopter, the flow field around rotating blades of a rotor is highly three-dimensional and very complex. Depending on the flight conditions, helicopter blades work across a wide range of angles of attack (AoA) and airspeeds. In hover, the blades move at the rotational relative wind (as a result of a movement of an airfoil through the air). Thrust loading and induced velocity are azimuthally symmetric. In forward flight, the relative airspeed is a combination of the rotational velocity of blades and forward flight speed. In this case, the nonuniform distribution of the induced velocity (Fig.1.) and angle of attack (Fig. 2.) over the rotor disc is observed. Dissymmetry of thrust between advancing and retreating side of the rotor disc occurs. In the case of helicopters, cyclic pitch control is used to offset asymmetric lift in forward flight. Retreating blade is pitched to higher alpha to compensate for lower effective dynamic pressure. Depends on a state of forward flight, flow conditions corresponding to attached flow, light stall or deep stall [2, 4, 5, 7].

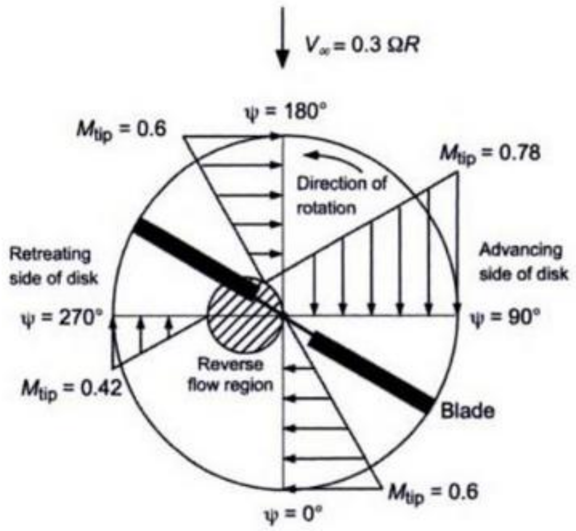


Fig. 1. Velocity distribution per rotor revolution in forward flight [5]

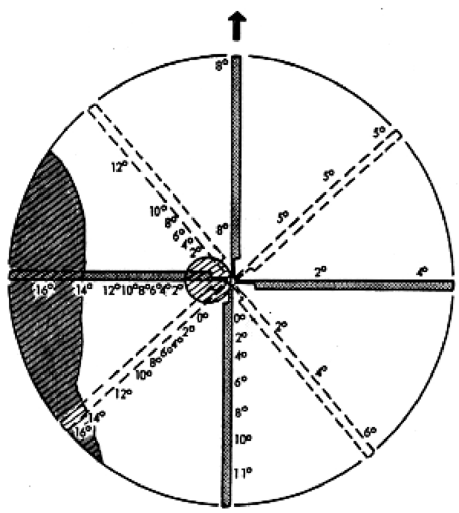


Fig. 2. Angle of attack distribution per rotor revolution in forward flight [6]

The stall phenomenon appears when the critical angle of attack is exceeded and occurs first on the retreating blade in forward flight due to cyclic pitch oscillation. Retreating blade dynamic stall is more likely to occur when the following conditions exist: high gross weight, high airspeed, low rotor RPM, high density altitude or turbulent air. This paper present the results obtained for stall conditions and outside of its occurrence. The simulation of flow around a rotor blade shows features of the flow field.

2 Methods of investigations

The nature of the flow field around a section of a rotor blade based on the Sikorsky SSC-A09 airfoil was investigated. The test article of the research was a section which found in the tip region of the main rotor blade of UH-60M Black Hawk helicopter. Study was performed using experimental and computational methods. Experimental analysis was made in the Ohio State University 6 x 22 in. unsteady transonic wind tunnel (Fig. 3.). The test section of the tunnel is 6 (width) x 22 (height) x 44 (length) inch. The two parameters: Mach number (from 0.18 to 1 in steady conditions) and Reynolds number can be modified over a range (Fig. 4). The tunnel is equipped with mechanisms to oscillate of the airfoil pitch and free stream Mach number. The working section is fitted out with a perforated floor and ceiling walls (6 % porosity) for minimizing Mach wave reflections. The wind tunnel is powered by a pair 21 m^3 tanks pressurized up to 15.5 MPa.

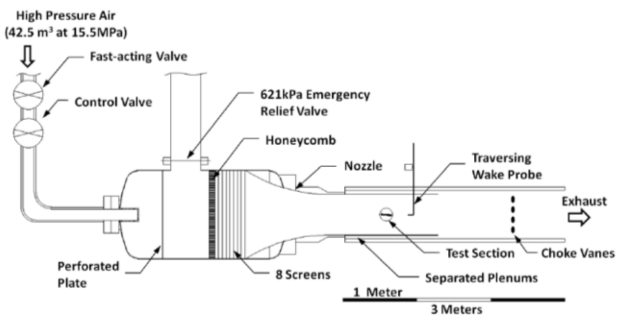


Fig. 3. Schematic of OSU 6 x 22 in wind tunnel [3]

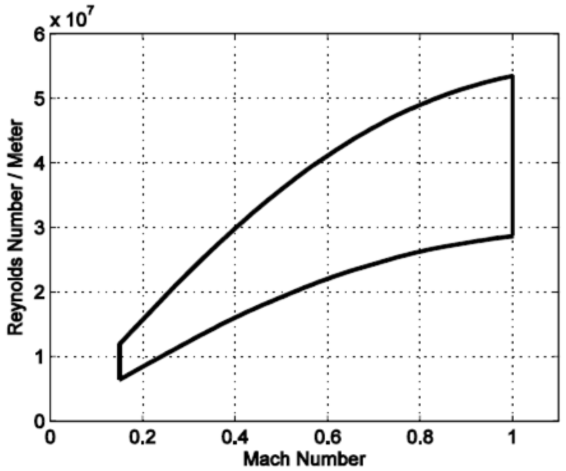


Fig. 4. Range of Re and Ma numbers OSU 6 x 22 in. tunnel [3]

Study of the flow around a section of blade was performed at attack angles between 0 and 20 degrees and free stream Mach number Ma=0.2, 0.4, 0.6. A scale of the test model is shown in Fig. 5.

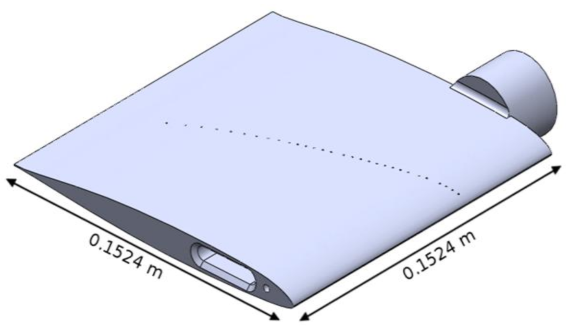


Fig. 5. A size of test model

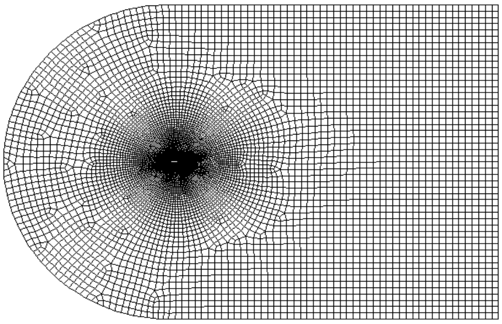
Research in the wind tunnel was performed using two methods: oil visualization (over a wide range of alpha and Ma) and pressure measurements (Ma=0.4). Oil visualization has been done using chalk dust on oil which was distributed on the top surface of the airfoil. Fig. 6. illustrates the wing section before run. Process of the test was recorded using the high speed camera.

Fig. 6. The wing section before run

A numerical analysis has been performed using Computational Fluid Dynamics tools. Simulations were carried out using ANSYS FLUENT code [1]. This numerical algorithm based on the finite-volume method. The compressible fluid flow was simulated. The Spalart-Allmaras turbulence model was implemented.

Four computational models were prepared for analysis:

- 2 D farfield (Fig. 7a.)
- 2D airfoil in wind tunnel with solid walls (Fig. 7b.)
- 3D wing in wind tunnel with solid walls (Fig. 7c.)
- 3D wing in wind tunnel with perforated walls (Fig. 7d.)

a)


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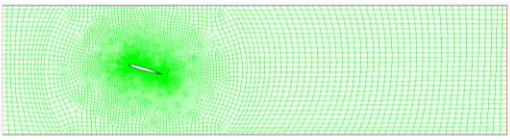

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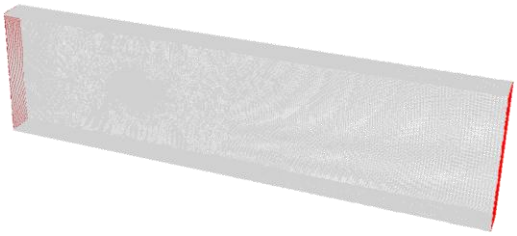

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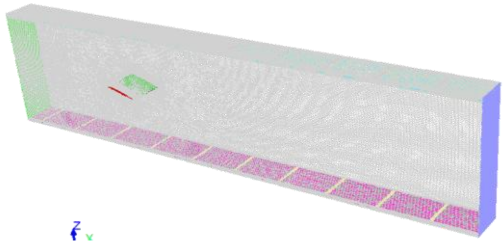
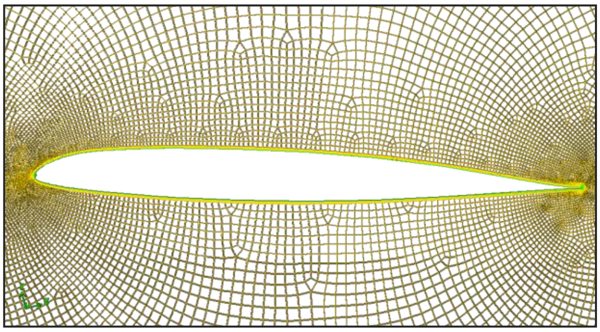


Fig. 7. Computational models

2D simulations are the equivalent to an infinite wing. „2D farfield" model represents the free flight conditions. 3D models were created for investigate differences between an infinite wing and a wing with short aspect ratio. Computational models allowed comparing the free-flight conditions with wind tunnel conditions. The computational mesh near the airfoil surface is presented in Fig. 8.

a)


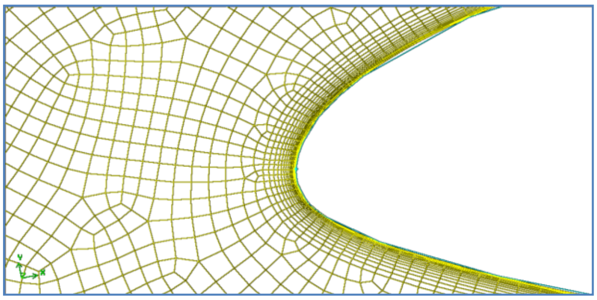
b)


Fig. 8. A computational grid: a) around the airfoil; b) around a nose of the airfoil

3 Comparison of quantitative results

In the first part of the study, the quantitative analysis was conducted. Pressure measurements in a transonic wind tunnel were performed at Mach number of 0.4 and at several angles of attack. Then, CFD calculations using ANSYS FLUENT software were made for the same airspeed value. The following graph of lift coefficient versus angle of attack (Fig. 9.) shows a comparison of the computational and experimental results. The results obtained using both methods are very similar. Both methods show the stall region for the same range of angles of attack.

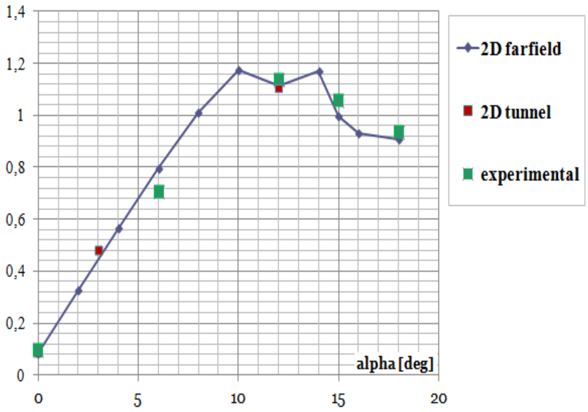


Fig. 9. Lift coefficient characteristic for Ma=0.4

4 Quantitative analysis of the flow around the SSC-A09 airfoil

The main goal of this work was a qualitative analysis of the flow around the SSC-A09 airfoil. Experimental oil visualization technique and CFD flow visualization showed the nature and features of the flow around the airfoil depend on airspeed and AoA. Flow conditions corresponding to attached flow, light stall and deep stall were simulated using wing tunnel tests and CFD.

At low values of angle of attack, stream wise flow is observed on the top surface of the airfoil. No evidence of three-dimensional flow. Experimental (Fig. 10.) and computational (Fig. 11.) visualization showed attached flow at low alpha. Smooth, undisturbed flow over the airfoil noted using both research methods.

Fig. 10. Oil visualization for Ma=0.4

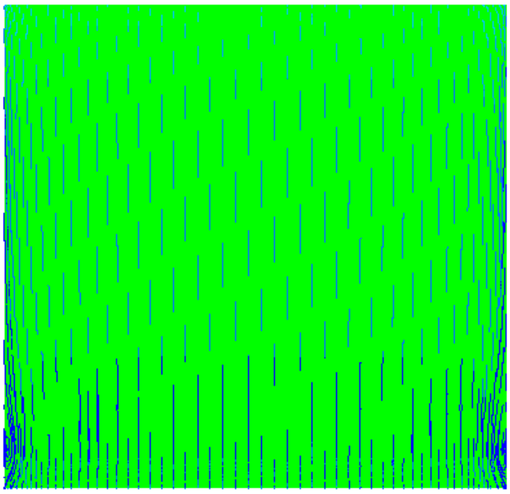
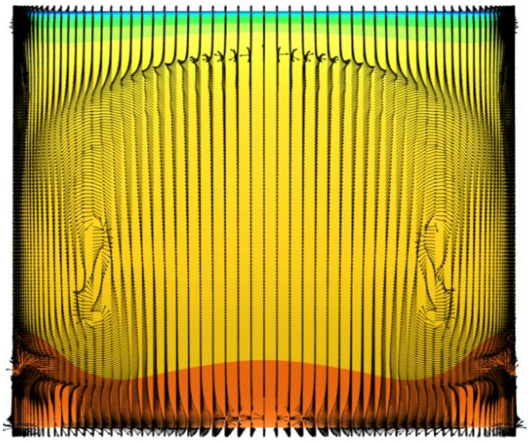


Fig. 11. Computational visualization for Ma=0.4

Stall conditions observed close to 15 degree angle of attack. 3D flow post-stall with separation line and reversed flow in the central part of the wing noted.

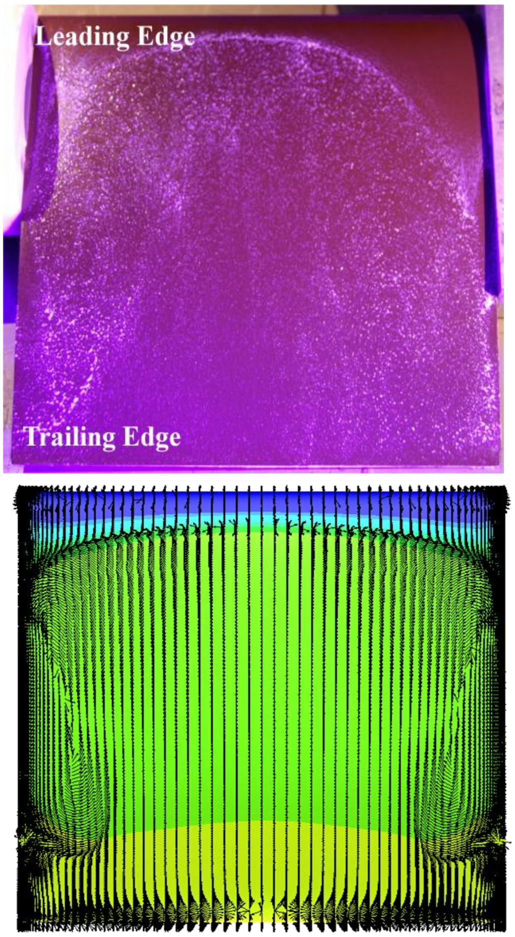
a) 



b)

Fig. 12. A flow visualization – Ma=0.2, alpha=15 deg

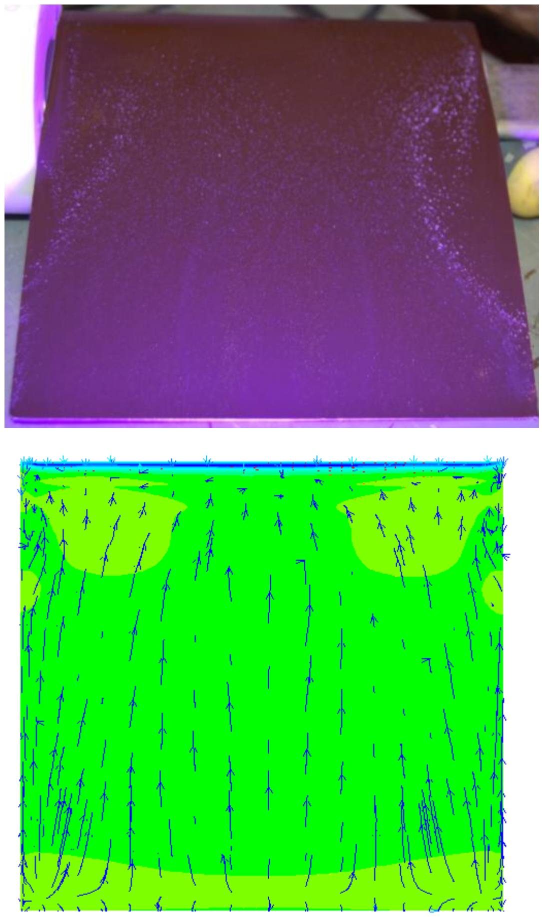
Computational and experimental results had shown a similar pattern on the top surface of the airfoil. At angles of attack higher than 14 deg 3D unsteady, disturbed flow observed. At Mach number of 0.6 (Fig. 14.) in both methods reversed flow is observed.



a)

b)

Fig. 13. A flow visualization – Ma=0.4: a) alpha=16 deg, b) alpha=15 deg



a)

b)

Fig. 14. A flow visualization – Ma=0.4: a) alpha=18 deg, b) alpha=15 deg

5 Conclusions

Research results presented in the paper shows the comparison of two methods: experimental and computational. The quantitative and qualitative data provided information about the nature of the flow around the SSC-A09 airfoil. Attached flow, light stall and deep stall conditions were observed. The obtained results were used to calibrate the computational models that can be used to further work (an analysis with Mach or pitch oscillation).

6 References

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