Al academia journal for Basic and Applied Sciences (AJBAS) volume 4/No. 1 – 2022 April

The Effects of Sweep Angles and Sweep Angle Locations on twisted blade of Helicopter

Hweda Muftah Sharif[1]
Ali Mohamed Belhaj[2]
Khaled.A.Aljaly[3]
[1]Technical College of Civil Aviation, Esbea, Libya
[2]Higher Institute of Science and Technology, Zahraa, Libya
[3]Afriqiyah Airways Company, Tripoli, Libya
hwedasharif@gmail.com
Ali.belhag@yahoo.com
Kaljaly0@gmail.com

Abstract

The effect of sweep angles and locations of sweep angle of a helicopter rotor blade is analyzed in terms of the rotor thrust, torque and Figure of Merit under hover condition. The main focus to improve rotor thrust. The Reynolds Averaged Navier-Stokes computations are done using the FINE/turbo flow solver developed by NUMECA International. The Spalart-Allmaras turbulence model is used to calculate the viscosity. The baseline blade is selected as the Black Hawk UH60A rotor blade. The results of the study showed that, the effect of different sweep angles and locations on the twisted UH60A blade is a little effect in the thrust and figure of merit. Moreover, the effect on torque was much more pronounced than the effect on thrust. A decrease of around 4 % in torque was possible for the UH60A blade.

Keywords: Helicopter rotor blade, hover condition, CFD.

الملخص

يتم تحليل تأثير الزوايا المائلة الى الخلف وموقعها لشفرة دوار المروحية من حيث قوة الدفع الدوار وعزم الدوران وشكل جدارة الاداء تحت ظروف التحويم. الهدف الرئيسي لتحسين دفع الدوار . تم إجراء حسابات Reynolds Averaged Navier–Stokes باستخدام محلل تدفق FINE / Turbo الذي طورته شركة NUMECA International. يستخدم نموذج الاضطراب Spalart–Allmaras لحساب اللزوجة. يتم تحديد الشفرة الأساسية على أنها الشفرة الدوارة Black Hawk UH60A. أظهرت نتائج الدراسة أن تأثير الزوايا ومواقعها المختلفة على شفرة UH60A الملتوية له تأثير ضئيل في قوة الدفع وشكل الجدارة. علاوة على ذلك ، كان التأثير على عزم الدوران أكثر وضوحًا من التأثير على قوة الدفع. كان من الممكن حدوث انخفاض بنحو 4٪ في عزم الدوران الشفرة UH60A.

الكلمات الدالة: شفرات دوار المروحية , CFD , حالة التحويم

1. Introduction

CFD has been used as a strong tool to study, analyze and improve the helicopter rotor performance. Many researchers have used CFD tools to study the performance of Black Hawk UH60A helicopter blade.

Ilkko et al. [1] conducted simulations based on Reynolds-averaged Navier-Stokes equations, which they solved based on the available data of the UH-60A helicopter. The computations were conducted for validating FINFLO flow solver applying several turbulence models.

Hamid F., Ahmad [2] used a latest free-wake CFD process to calculate the aerodynamic loads for two-bladed helicopter rotors during a hovering flight and compared their numerical calculations with the experimental data pertaining to the pressure distribution of the Caradonna-Tung UH-60 blade.

Seokkwan et al. [3] conducted unsteady turbulent flow simulations for investigating the turbulence models and their impact on the predicting efficiency of the isolated XV-15 hovering rotor. Many previous literature studies used UH-60 helicopter rotor for the research. The validation of its 3D CFD framework was accomplished through comparing the predictions pertaining to a baseline UH-60A rotor with the experimental data.

Yashwanth R. [4] tested slatted UH-60A rotor blade with 40% span-slatted airfoil section and a couple of varying slat configurations. Patrick M. Shinoda [5] evaluated NASA Ames 80x120 feet wind tunnel for hover testing. He compared the rotor performance data with the predicted data, flight data of UH-60 aircraft and UH-60 model-scale data, and all the data showed good agreement when compared to the full-scale data. Choi et al. [6] used time-spectral and discrete adjoint-based methods for optimization of UH-60 rotor blade reducing torque without losing thrust.

Many studies use UH60A rotor blade as baseline [7-11]. The baseline blade in this study has also been selected same as that blade. In the current study, the effects of different sweep angles, sweep angle locationn configurations on the performance of helicopter rotor blade is investigated. The baseline blades is the twisted UH60A rotor blade. All the computations are performed by solving the Reynolds Average Navier Stokes (RANS) equations with implemeting the Spalart-Allmaras turbulence mode and the results are presented in terms of change in thrust, torque and Figure of Merit.

2. Methodology

2.1 Flow Solver

All the computations in this study are done using the commercial CFD package FINE/Turbo [12] developed by Numeca International. The FINE/Turbo solver is a three-dimensional, density-based, structured, multi-block finite volume code.

The mesh around the blades is generated using O4H grid topology. The grid generation software employed is IGG/AutoGrid5 [13] of Numeca International. A schematic of the 5-block mesh is shown in Figure1 and described below.

1. The O block around the blade.
2. The H block upstream the leading edge of the blade.
3. The H block downstream the trailing edge.
4. The H block up to the blade section.
5. The H block down to the blade section

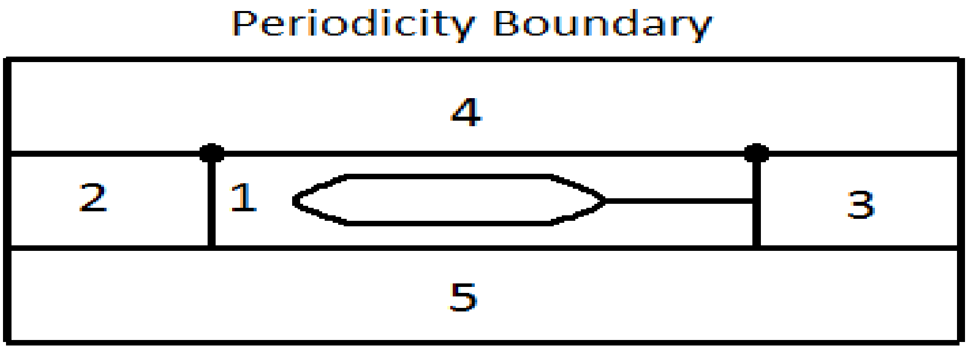

Figure 1. (O4H) grid block structure used

2.2 UH-60A Rotor Blade

The case is the UH-60A Black Hawk helicopter rotor which has 4 twisted blades with 20 degrees sweep at 92% span location. The UH-60A rotor has been studied in many researches [14-18]. The UH-60A rotor blade consists of two different airfoils distributed as follow: SC1095 airfoil in the root and tip regions and the SC1094R8 airfoil in the mid-span region. The geometric sketch of the blade is shown in Figure 2.

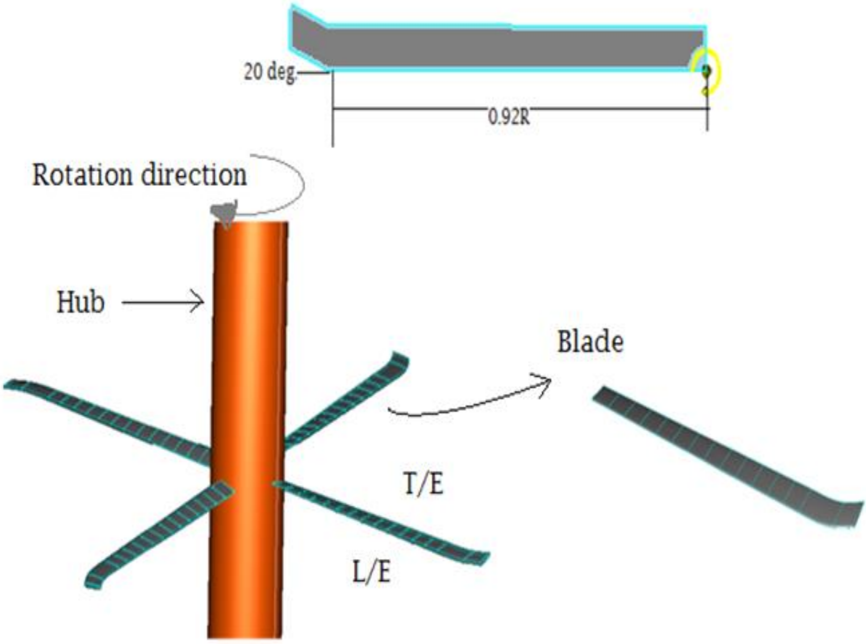

Figure 2. 3D UH-60A helicopter blade geometry.

The mesh was generated for a single blade under periodic conditions to account for the other blade. The number of nods on the entire mesh including the blade and external flow is about 9 million nodes. Mesh around the UH-60A blade shown in Figure 3

The thickness of the first cell to the wall was kept at (2.0 x10^{-6} m) so that the y^+ value is close to 1, which is suitable for the implemented Spalart-Allmaras turbulence model and the low Reynolds number. The meshes for all the cases are generated in the same way and working time for one grid is about 3hrs.The mesh around the blade is shown in Figure 4.

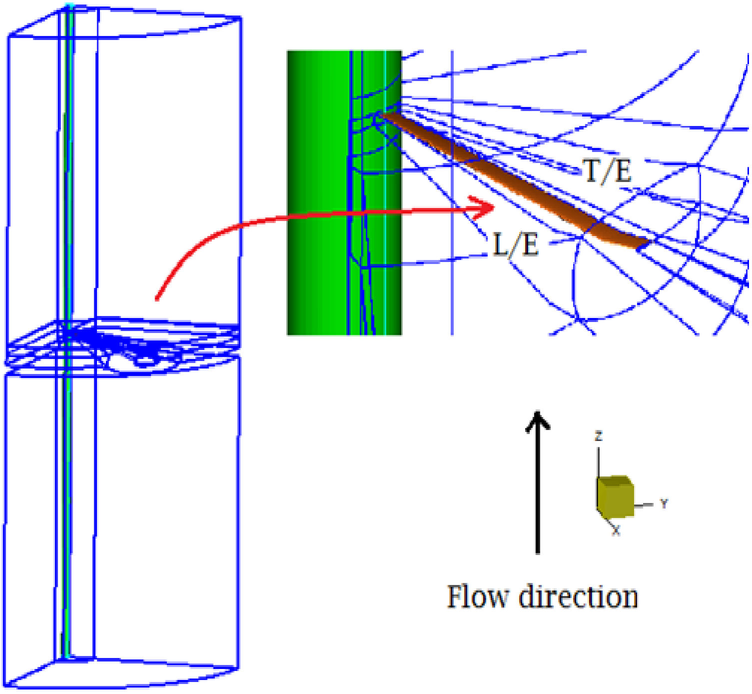

Figure 3: Figure 4: Mesh around the UH-60A blade.

The CFD results are validated against the experimental data using terms of the pressure distribution coefficient on different sections along the blade in Figure 5. There is a good match in general between the CFD results and the experimental data with small discrepancy at the outboard spanwise sections.

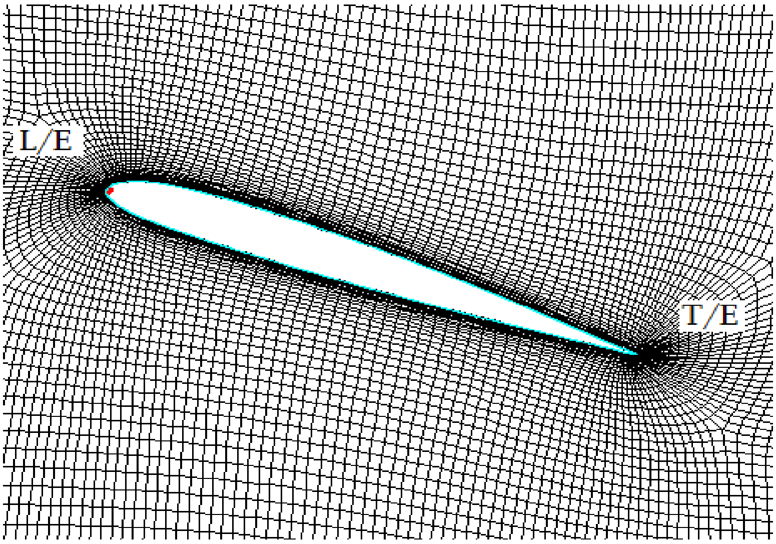

Figure 4 Mesh around the UH-60A blade

The Y^+ value located between 0.75 and 2 in the wall blade. Such range of is suitable for the tested Spalart-Allmaras turbulence model, the Figure 6 is show that in below.

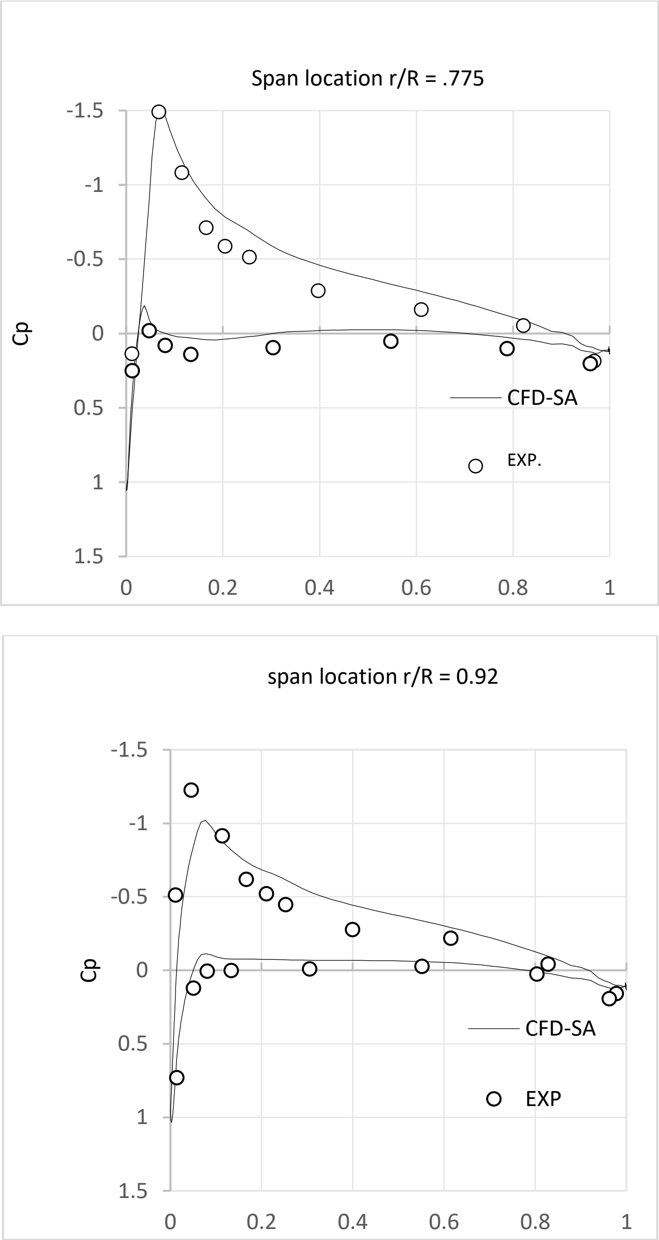

Figure 5: Comparison of Pressure distribution coefficients for UH-60A.

3. Cases Analyzed.

As mentioned before, the UH-60 Black Hawk helicopter blade was chosen for the cases study. The shape of blade and its tip are significant for the helicopter's aerodynamic performance. The blade tips encounter the peak pressure and high Mach number while strong trailing tip vortices are produced.

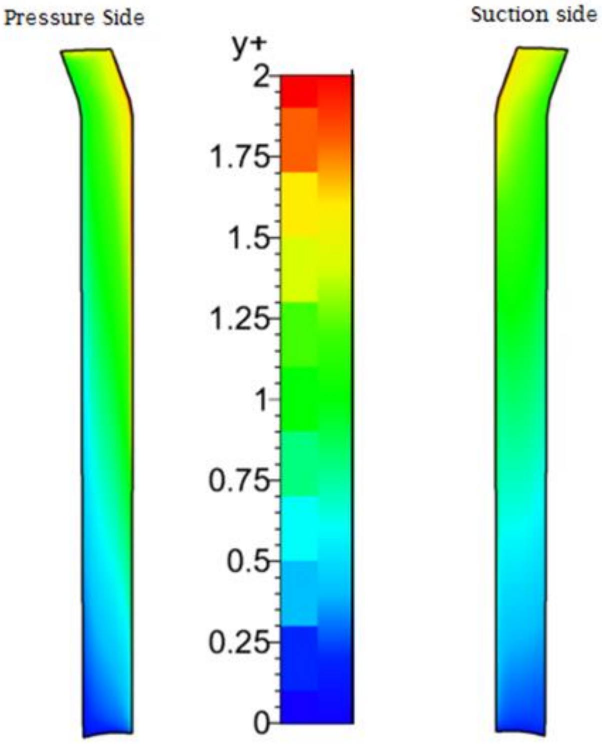

Figure 6: Y^+ Value for UH-60A helicopter

A poor tip design causes serious implications for the performance of a rotor. In this section, the changes in the shape of the blades and will be discussed of analyzed the effect of the blades' sweepback angle and location angle of UH60A blade on the rotor performance and study its impact on the rotor thrust and torque. All those studies are conducted under the hovering condition.

3.1 Sweep angle and sweep location for UH-60A.

Various geometries of the baseline blade of UH-60A rotor with different sweep locations (80%, 90% 92% and 94% along the span) and for different sweep angles (5, 10, 15, 20, 25 and 30 degrees) were generated at the same collective pitch angle. Some of the generated cases are shown in Figure 6.

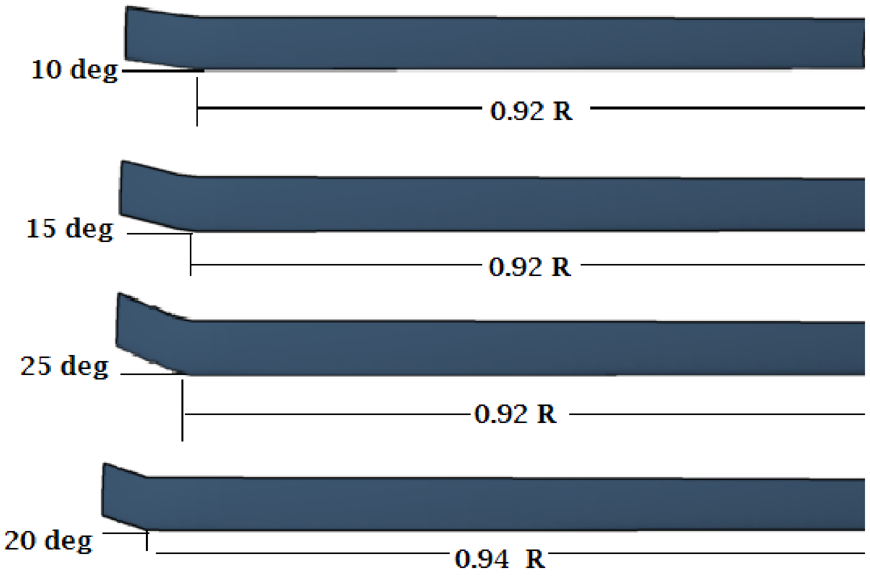

Figure 6. Different sweep angles and sweep locations of UH-60A.

All the computations are carried out at rotational speed of 1425 RPM, Collective pitch angle of 10.47 degrees and coning of -2.31 degrees.

The helicopter rotor blade efficiency during hover condition is usually expressed in terms of Figure of Merit (FM). The Figure of Merit is an indication of both the thrust and torque (Eqn. 1)

$$FM = \frac{C_T^{3/2}}{\sqrt{2}C_Q} \qquad (1)$$

Where $\boldsymbol{C_T}$and $\boldsymbol{C_Q}$are the thrust and torque coefficients respectively.
The results of the percentage increase in thrust, percentage decrease in torque and percentage increase in figure of merit with respect to the baseline blade are summarized in Table 1. We should refer that the baseline blade has a sweep angle of 20° located at 92% span.

Table 1. The results of thrust, torque and figure of merit (F.M) for different cases generated from UH-60A blade.

Sweep back Angle	Sweep Location r/R	F.M	Increase Thrust (%)	Decrease Torque (%)
0	0	0.730	-0.466	0.036
5 degree	90%	0.698	-0.699	-4.173
	92%	0.732	-0.513	0.468
	94%	0.733	-0.559	0.540
10 degree	90%	0.732	-0.466	0.288
	92%	0.709	-2.657	0.468
	94%	0.733	-0.466	0.432
15 degree	90%	0.735	0.047	-0.036

	92%	0.736	0.047	0.072
	94%	0.737	0.047	0.216
20 degree	90%	0.729	-0.466	-0.072
	92%	**0.731**	**baseline**	
	94%	0.731	-0.420	0.180
25 degree	90%	0.732	-0.093	-0.252
	92%	0.733	-0.047	-0.216
	94%	0.734	-0.093	0.000
30 degree	80%	0.734	0.420	-0.719
	90%	0.730	-0.233	-0.288

From the results mentioned above, there is a little change in the thrust and figure of merit for the different sweep and location angles. This might be due to the fact that the UH-60A blade is already an optimized commercial blade. And improving an optimized blade is not an easy task.

4. Conclusion.

In this study, the effect of sweepback angle and sweepback angle location for UH60A blade rotor has been analyzed in terms of thrust force, Torque and figure of merit. Analyses have been performed for the same rotational speed value. Various cases are generated by allowing the change sweepback angle and angle locations to tip rotor. The results obtained showing that varying had effects on rotor performance. It was observed that little increase in the value of thrust and figure of merit and change in value of torque. In the fact the blade of UH60A it is optimum design.

5. References.

[1]. Juho Ilkko, Jaakko Hoffren and Timo Siikonen,” Simulation of a helicopter rotor flow,” *Journal of Structural Mechanics*, Vol. 44, No 3, pp. 186 – 205, 2011.

[2]. Hamid Farrokhfal and Ahmad Reza Pishevar, ”A New Coupled Free Wake-Cfd Method For Calculation Of Helicopter Rotor Flow-Field In Hover,” J. Aerosp. Technol. Manag., Vol. 6, No. 2, pp.129-147, 2014.

[3]. Seokkwan Yoon, Thomas H. Pulliam, and Neal M. Chaderjian, ”Simulations of XV-15 Rotor Flows in Hover Using OVERFLOW,” 5th Decennial AHS Aeromechanics Specialists Conference; San Francisco, CA; January 22-24, 2014.

[4]. Yashwanth Ram Ganti, ”CFD Analysis of a Slatted UH-60 Rotor in Hover,” Master of Science Thesis, University of Maryland, USA, 2012.

[5]. Shinoda P. M., Yeo H. and Norman, T. R., “Rotor Performance of a UH-60 Rotor System in the NASA Ames 80-by 120-Foot Wind Tunnel," Proceedings of the 58th Annual American Helicopter Society Forum, Montreal, Canada, June 11-13, 2002.

[6]. Seongim Choi, Kihwan Lee, Mark M. Potsdam and Juan J. Alonso, “Helicopter Rotor Design Using a Time-Spectral and Adjoint-Based Method,” Journal Of Aircraft, Vol. 51, No. 2, pp. 412-423, 2014.

[7]. M. Dinar, A. Leminos and M. Shephard. “Adaptive Solution Procedures for Rotorcraft Aero-dynamics,” Rensselaer Polytechnic Institute, Rotorcraft Technology Center, Troy, NY, USA,1997.

[8]. M. Potsdam, H. Yeo and W. Johnson “Rotor Airloads Prediction Using Loose Aerodynam- ical/Structural Coupling.” American Helicopter Society 60th Annual Forum, Army/NASA Rotorcraft Division Aeroflightdynamics Cirectorate (AMRDEC) U.S. Army Research, De-velopment, and Engineering Command, Moffett Field, CA, USA, 2004.

[9]. M. Potsdam, H. Yeo and W. Johnson. ”Rotor Airloads Prediction Using Loose Aerodynami- cal/Structural Coupling.” Journal of Aircraft, Vol. 3, No. 43, pp.732 - 742, 2006.

[10]. A. Datta, “Fundamental Understanding, Prediction and Validation of Rotor Vibratory Loads in Stedy Level Flight.” Doctoral Thesis, University of Maryland, College Park, MD, USA, 2004.

[11]. W. G. Bousman. “Aerodynamic Characteristics of SC1095 and SC1094 R8 Airfoils,” NASA TP-2003-212265, Aeroflightdynamics Directorate U.S. Army Research, Development, and Engineering Command Ames Research Center Moffett Field, CA, USA, 2003.

[12]. NUMECA International, FINETM/Turbo Software Package, ver.11.2rc, User Manual, 2017.

[13]. NUMECA International. IGGTM/AutoGrid5TM Software Package, ver.11.2rc, User Manual, 2017.

[14]. M. Dinar, A. Leminos and M. Shephard. “Adaptive Solution Procedures for Rotorcraft Aero-dynamics,” Rensselaer Polytechnic Institute, Rotorcraft Technology Center, Troy, NY, USA,1997.

[15]. M. Potsdam, H. Yeo and W. Johnson “Rotor Airloads Prediction Using Loose Aerodynam- ical/Structural Coupling.” American Helicopter Society 60th Annual Forum, Army/NASA Rotorcraft Division Aeroflightdynamics Cirectorate (AMRDEC) U.S. Army Research, De-velopment, and Engineering Command, Moffett Field, CA, USA, 2004.

[16]. M. Potsdam, H. Yeo and W. Johnson. ”Rotor Airloads Prediction Using Loose Aerodynami- cal/Structural Coupling.” Journal of Aircraft, Vol. 3, No. 43, pp.732 - 742, 2006.

[17]. A. Datta, “Fundamental Understanding, Prediction and Validation of Rotor Vibratory Loads in Stedy Level Flight.” Doctoral Thesis, University of Maryland, College Park, MD, USA, 2004.

[18]. W. G. Bousman. “Aerodynamic Characteristics of SC1095 and SC1094 R8 Airfoils,” NASA TP-2003-212265, Aeroflightdynamics Directorate U.S. Army Research, Development, and Engineering Command Ames Research Center Moffett Field, CA, USA, 2003.