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STUDY OF FLOW SEPARATION BETWEEN TWO AXIAL COMPRESSOR BLADES

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دراسة أنفصال الجريان بين ريشتي الضاغطة المحورية

رسالة مقدمة الى
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تقدم بها المهندس

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

((وَعَلَّمَكَ مَا لَمْ تَكُن
تَعْلَمُ وَكَانَ فَضْلُ اللَّهِ
عَلَيْكَ عَظِيمًا))

صدق الله العظيم

سورة النساء (١١٣)

Dedication:

To:

The candle lightening my way,
the most merciful heart,
who inspired my thinking,
the person who deserves
to be perfect
my mother.

SABAH

February-2008

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ABSTRACT

The effect of two-dimensional, steady, incompressible and isothermal flow separation on the performance of a cascade (blade-to-blade configuration) of **NACA 65_(12)10** blade base profile was studied with 30° camber angle. The effect of stagger angle on the flow separation was considered.

An experimental and theoretical investigation for the flow between two axial compressor blades has been carried out in this work.

The experimental work includes the fabrication of three blades from wood, each having a chord (100mm) but one of these blades having a span of (90mm) for smoke tunnel testing and the other two blades having a span of (380mm) for wind tunnel testing. The two blades were connected by suitable mechanism in order to be fixed in the wind tunnel protractor and rotated in the required stagger angle.

The blade to blade configuration was tested in an open type low-speed subsonic wind tunnel of maximum velocity (35 m/s) and for Reynolds number ($Re = 239605$) based on maximum velocity and airfoil chord length. The total and static pressures are measured at selected points between the two blades for a stagger angle of (4° , 0° , -4° , -8° , and -12°) by using multi-tube manometer and a pitot static tube. The small blade (90mm span) is tested in the smoke tunnel to visualize the real behavior of flow separation clearly.

The theoretical work includes using the computer program **FLUENT (V6.2)** to simulate the flow between the two blades

This study shows that the flow separation begins when the blade-to-blade configuration is inclined by a stagger angle of (-4°) on the suction side of the lower blade at a position (96%chord experimentally and 98%chord theoretically). Then, the separation zone increases with increased stagger angle (in clockwise direction) and reach to the position

(61%chord experimentally and 63%chord theoretically) at a stagger angle (-12⁰).These results are validated by a smoke tunnel tests.

This separation effects on the performance of a blade-to-blade configuration and then affects the compressor performance where the pressure ratio (P_{s_e} / P_{s_m}) decreases when the separation zone increases. By using curve fitting method for polynomial distribution between the pressure ratio and stagger angles, the concluded mathematical relationship after then the range of stagger angle is calculated where this range (from -18⁰ to 36⁰). The flow behavior between two blades shows that the blade-to-blade configuration works as a nozzle-diffuser.

The experimental results were compared with the theoretical results and good agreement was obtained.

The results of the present study are compared with previous published results and good agreement was obtained.

الخلاصة

تم في هذا البحث دراسة تأثير انفصال الجريان على أداء الريشتين المتعاقبتين للضاغطة المحورية عند الانحراف بزواوية معينة مع الوتر ، الريشتين من نوع [NACA 65_(12)10] مع تحذب دائري ، زاوية التحذب 30^0 .

في هذا البحث تم دراسة عملية ونظرية للجريان المضطرب بين ريشتي الضاغطة المحورية. الدراسة العملية تتضمن تصنيع ثلاثة نماذج من ريش الضاغطة المحورية من نوع [NACA 65_(12)10] من مادة الخشب، وتر كل ريشة (100 ملم) لكن احدى الريش ذو باع (90 ملم) لاختبارات النفق الدخاني والريش المتبقيتين ذات باع (380 ملم) لاختبارات النفق الهوائي. تربط الريشتين المستخدمتين لاختبارات النفق الهوائي بالية مناسبة لكي تثبت بمنقلة النفق وبالتالي يمكن الحصول على الزاوية المراد دراسة الجريان عندها.

تم اختبار متعاقبة الريشتين في نفق هوائي تحت صوتي واطى السرعة ذو سرعة قصوى (35 م /ثا) وهي السرعة التي تم عندها اجراء التجارب وللعدد رينولد(Re=239605) المحسوب على اساس السرعة القصوى للنفق الهوائي وطول وتر الريشة حيث تم قياس الضغط الكلي والضغط الاستاتيكي للنقاط المختاره بين ريشتي الضاغطة لخمس زوايا انحراف (4,0,4,-8,-12-) باستخدام مانوميتر متعدد الانابيب وأنبوب بيتوت-أستاتي. وكذلك تم اختبار الريشة الثالثة (ذو عرض 90 ملم) بأستخدام النفق الدخاني لرؤية السلوك الحقيقي لأنفصال الجريان بوضوح.

الدراسة النظرية تتضمن أستخدام برنامج (GAMBIT) لتوليد الشبكة (Mesh Generation) بين الريشتين حيث أن نوع التقسيم هو (Pave) وتم تعميم التقسيم بأستخدام طريقة (L-W Laplacian).

تم اعتبار الجريان بين الريشتين مستقر، لا أنضغاطي، وبثبوت درجة الحرارة وتمت محاكاته باستخدام برنامج (FLUENT V6.2) حيث أن طريقة الحل العددي العامة المستخدمة في هذا البرنامج هي طريقة الحجم المحدده (control volume method) ونموذج اضطراب الجريان المستخدم بموديل ال (K-ε) (Turbulence Model K-ε). تم استخدام نظام خوارزمي (SIMPLE algorithm) في دمج معادلة الأستمرارية ومعادلات الزخم في هذا البرنامج.

أظهرت النتائج بأن الانفصال يبدأ عندما تكون زاوية الانحراف (-4) حيث يحدث على سطح العلوي للريشة السفلى وبمسافة (96% من الوتر عمليا" و 98% من الوتر نظريا") من الدخول الى الخروج للمتعاقة، وبعد ذلك تزداد منطقة الانفصال بأزدياد زاوية الانحراف (stagger angle) (بأتجاه عقرب الساعة) حتى تصل الى (61% من الوتر عمليا" و 63% من الوتر نظريا") من الدخول الى الخروج عند زاوية انحراف (-12) وهذا ما يوضحه اختبار النفق الدخاني. يؤثر الانفصال على أداء الريشتين المتعاقبتين وبالتالي على أداء الضاغطة المحورية حيث تقل نسبة الضغط (الضغط الستاتيكي الخارج الى الضغط الستاتيكي الداخل) بأزدياد منطقة الانفصال. باستخدام طريقة تطابق المنحنيات لتوزيع متعددة الحدود بين نسبة الضغط الاستاتيكي وزاوية الانحراف للريشتين المتعاقبتين، أستنتجت علاقة رياضية بين نسبة الضغط الاستاتيكي وزاوية الانحراف وبعد ذلك يتم حساب مدى زوايا الانحراف التي تصمم على أساسها تلك الريشة. أما سلوك الجريان بين الريشتين يثبت بأن الريشتين المتعاقبتين تعملان كبوق متقارب- متباعد. تمت مقارنة النتائج العملية مع النتائج النظرية، وجد تقارب جيد بينهما. ثم تمت مقارنة النتائج العملية والنظرية في هذا البحث مع نتائج عملية ونظرية لبحوث سابقه، وجد أيضا" تقارب جيد بين تلك النتائج.

Nomenclature

English Symbols

Symbol	Description	Units
A	Test section area	m ²
B	Relative velocity	m/s
b	Model span	m
C	Blade chord line	m
C_1, C_2, C_μ	Constants in turbulence model	-
C_3, C_4, C_s	Constants used in equations (3-9h), (3-9i)	-
C_D	Drag coefficient (from wind tunnel calculation)	-
C_{L0}	Design lift coefficient	-
c	Velocity	m/s
D	Blade linear velocity	m/s
d, nd, zd	Dimension of pitot static tube	m
E	Constant used in the low of the wall	-
e	Correction coefficient	-
e_0	Action of static pressure holes distance	-
F	Force	N
G_k	Production term of kinetic energy	kJ
g	Acceleration due to gravity	m/s ²
h_t	Test section height	m
K	Kinetic energy of turbulence	m ² /s ²
K_b	Body shape factor	-
k	von Kármán constant	-
L_c	The characteristic length	m
mv	Model volume	m ³
n	Local coordinate normal to the wall	m
P	Pressure	Pascal
R	Gas constant	J/kg.K
Re	Reynolds number	-
R_t	The turbulent Reynolds number	-
S	Space between two blades	mm
$S_{P,k}, S_{U,k}$	Source terms	m ² /s ²
T	Air temperature	K
T_u	The turbulence intensity	-
t	Time coordinates, Model thickness	s

t_m	Model thickness	mm
U_1	Velocity component parallel to the wall at first node	m/s
U_*	Shear velocity	m/s
u, v, w	Velocity components in x, y and z directions	m/s
u_x	Friction or shear velocity	m/s
$Y_{M,k}$	Discretized k -equation	kg/m ³
x, y, z	Coordinates in X, Y and Z- directions	m

Greek Symbol

Symbol	Description	Units
α	Flow angle	degree
β	Blade angle	degree
γ	Specific heat ratio	-
ΔH	Water head in manometer	o ₂ cmH
ΔV	Elementary Area of control volume	m ²
ε	Dissipation rate of turbulent kinetic energy	m ² /s ²
ε_o	Overall Correction Coefficient	-
ε_{sb}	Closed Coefficient for Solid-Blockage	-
ε_{wb}	Wake Blockage Coefficient	-
θ	Stagger angle	degree
μ	Laminar viscosity	kg/m.s
μ_t	Turbulence viscosity	kg/m.s
ν	Kinematic viscosity	m ² /s
ρ	Density	kg/m ³
$\sigma_k, \sigma_\varepsilon$	Effective Prandtl numbers	-
τ	Shear stress	N/m ²
ϕ	Dependent variable	-
Ω	Distance action from tube to wall	
ω	Viscosity coefficients value	-

Superscripts

Symbol	Description
'	Fluctuation quantity
→	Vector
+	Indicates normalization that used in the law of the wall function
*	Fluctuating quantity of the last iteration, guessed values

Subscripts

Symbol	Description
a	Axial
cali	Calibrated
cell	Cell
d	Dynamic
e	Effective
mean	Mean value
p	Values at center of the control volume
s	Static
t	Total
un	Uncorrected
unca	Uncalibrated
w	Wall
water	Water
x, y, z	The quantity corresponding to x, y, z direction
τ	Shear
1	Inlet condition
2	Outlet condition

Abbreviations

Symbol	Description
A.C motor	Alternating Current Motor
CFD	Computational Fluid Dynamics
CPM	Central Processor Unit
LDV	Laser-Doppler Velocimetry
MSH	Mesh.
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
PIV	Particle Image Velocimetry
RNG	Renormalization group of $K - \varepsilon$
SIMPLE	Simi – implicit method for pressure linked equations
SIMPLEST	SIMPLE – Specially Treated (Newly developed)
2D	Two dimensional
2ddp	Two-dimensional double precision

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