AN INVESTIGATION OF THE SWIRLING FLOW THROUGH AN ANNULAR DIFFUSER

by

Mohamed Mohame Ali
IBRAHIM M. M. A. SHABAKA

B. Sc.(Mech. Eng.) Hons.
Cairo University

'Thesis submitted in accordance with the requirements of Ain Shams University for the degree of Master of Science in Mechanical Engineering.'

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Supervised by:

Prof. A.A.RIZK	Dr. M.R.A.SHAALAN
Professor, Mech. Dept., Faculty of Engineering, Ain Shams University	Lecturer, Mech. Dept., Faculty of Engineering, Ain Shams University

Mechanical Engineering Department
Faculty of Engineering
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بسم الله الرحمن الرحيم

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رسالة مقدمة من

مهندس ابراهيم محمد محمد على شبكه
بكالوريوس الهندسة الميكانيكية (مرتبة الشرف)
كلية الهندسة ــ جامعة القاهرة

للحصول على
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لجنة الحكم على الرسالة :

Examinars:

Prof.K.H. KHALIL ٢٩/٧/١٩٧٣
C.Eng.Ph.D.F.I.Mech.E.

استاذ دكتور خليل حسن خليل
استاذ ورئيس قسم الهندسة الميكانيكية كلية الهندسة
جامعة القاهرة

Prof.A.A. RIZK ٢٩/٧/٧٣
Ph.D., A.M.Inst. R.

استاذ دكتور عبدالمنعم احمد رزق
استاذ الآلات الحرارية بكلية الهندسة جامعة عين شمس

Dr.S.M.ABD-EL GHANI
B.Sc., Ph.D.Mech. Eng.

استاذ دكتور سمير محمد عبد الغنى
استاذ الآلات الحرارية المساعد بكلية الهندسة
جامعة عين شمس

P R E F A C E

This dissertation is submitted for the degree of Master of Science in the Faculty of Engineering of Ain Shams University.

The work described in this thesis was carried out, unless otherwise indicated, by the author in the Department of Mechanical Engineering, Faculty of Engineering, Ain Shams University and the Scientific Computation Centre of Cairo University from October, 1969 to May, 1973.

No part of this thesis has been submitted for a degree at any other university.

I. M.M. Shabaka

June, 1973.

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S U M M A R Y

This dissertation sets out to investigate the performance of an annular diffuser of cylindrical centre body (hub) and conical casing, in conditions of swirling flow over a range of Reynolds number. The cone angle of the casing is 15° and the overall area ratio is 7.13.

For the purpose of the present work a special test rig was constructed, consisting of an annular diffuser, a fan, and a swirl generator. The rig was also provided with suitable instrumentation. The value of Reynolds number was varied by changing the mass flow rate through the diffuser by means of a butterfly valve at fan discharge. The degree of swirl was controlled by means of a special mechanism connected synchronously to the swirl vanes.

Tests were carried out on the above diffuser at various degrees of swirl. In each test, the flow was surveyed at various sections along the diffuser length. In each survey, records of static pressure, total pressure, and yaw angle were taken at several positions along radius. From these measurements, the local, as well as the overall performance of the

diffuser were derived and discussed in detail. The behaviour of the observed performance was also interpreted in the light of the detailed picture of the flow that was obtained from measurements.

The non-viscous flow through the diffuser passage was calculated using the streamline-curvature approach. Results of this calculation were displayed in the form of meridional streamlines and axial velocity profiles. Also, the boundary layer development on the diffuser walls was computed and the predicted onset of separation was compared with observations.

Results of the present investigation indicate that:

(i) In general, there is a 'marked' effect of swirl on the overall performance of the annular diffuser. In particular the performance appears to improve for degrees of swirl below 20 but deteriorates thereafter.

(ii) There is a distinct effect of swirl on the onset of boundary layer separation from diffuser walls. At no swirl, separation takes place on the casing. At low and moderate swirls, separation starts on the hub then on the casing. At high swirls, separation is still on the hub but seems to disappear from

N O T A T I O N

a	acoustic velocity.
A	area , or
	function of δ, Π, ω, ε_w (See Chapter 5).
B	constant in the law of the wall.
c	velocity.
c_p	specific heat at constant pressure.
c_v	specific heat at constant volume.
C_{fs}	streamwise component of wall shear stress coefficient = $\tau_{ws} / \frac{1}{2} \rho U^2$
C_p	pressure recovery coefficient.
C_{pI}	ideal pressure recovery coefficient.
D	diameter.
E	non-dimensional rate of entrainment.
F	function of δ, Π, ω, ε_w (see Chapter 5).
G_1, G_2, ..etc.	Functions of Π, k (see Appendix D).
G_1', G_2', .etc.	= $dG_1/d\Pi$, $dG_2/d\Pi$, ...etc.(see Appendix D).
h_o	stagnation enthalpy.
H	boundary layer shape factor = δ_s^* / θ_{ss} (see Chapter 5).
$H_{\delta - \varepsilon_s^*}$	Heads entrainment shape factor = $(\delta - \varepsilon_s^*) / \theta_{ss}$ (see Chapter 5).
k	Von Karman constant.
K_1	convergence or divergence of streamlines at edge of boundary layer (Eq. 5.10.b).

,o	for condition with no swirl.
old	for old values before iteration.
r	for the radial direction.
ref.	for reference values.
s	for the streamwise direction.
x	for the axial direction.
y	for the circumferential direction.
w	for wall conditions.

<u>Superscripts</u> :

–	non-dimensional, or
	average value (Appendix B).
′	differentiated value.
•	time rate.

<u>Abbreviations</u>:

AR	area ratio.
AR_H	area ratio of Hoadley's diffuser (=4.61)(Ref.(16)).
D.E.	Differential Equation.
Eq.	Equation.
R_e	Reynolds number. $= \frac{C_{xi}(2\Delta r_i)}{\nu}$

Symboles and Abbreviations Used in Computer Output(Tables VI-VIII), and Flow charts (Figs. 10,12,14):

ABS.	absolute value
ALPHA	angle α
ANG	angle
BETA	angle ξ
CF	C_{fs}
COEF.	coefficient.
CP	C_p
CP1	$C_{p_{mass}}$ (Eq.A.1)
CP2	$C_{p_{area}}$ (Eq. A.2)
CP3	$C_{p_{swirl,\ mass}}$ (Eq.A.3)
CTH	c_y
CX	c_x
CXO	c_{xi}
CURVART1	r_{ci}/R
DALPHA	$\partial\alpha / \partial r$
DCX	$\partial c_x / \partial x$
DEG.	degree
DELTA	δ
DPHI/DR	$\partial \phi / \partial r$
DR	streamline shift ($r_{new} - r_{old}$)
DSTARX	δ^*

EF	$C_p / C_{pI} = \eta$
EF1	$C_{p_{mass}} / C_{pI} = \eta_{mass}$
EF2	$C_{p_{area}} / C_{pI} = \eta_{area}$
EF3	$C_{p\,swirl,area} / C_{pI} = \eta_{swirl,\ area}$
EPSILO	ε
F	$\tan\alpha$, or $[\rho\, c_m\, r_{new}\, \cos\phi]$
FI	$\int_0^r F\, dr$: mass flow rate included ~~for~~ from hub to (r)
GN	$\frac{1}{U}\frac{dU}{dn}$
GS	$\frac{1}{U}\frac{dU}{ds}$
H	H
ID	control variable
IS	control variable
K	no. of the annulus
KK	control variable
KN	K_1
KP/M2	k_p/m^2
LLL	Number of the radial calculating plane
M	M
P	p
PHI	ϕ
PI	π
POS.	position.
PRESS.	pressure.

P TOTAL	P_o
RAD.	radius,(r).
RE	R_e
RECOV.	recovery
RHO	ρ
RO	r_{ci}
RT1	r_{ci}
R2	r_{new}
T	T or t
TGT.	tangential
THETA11	θ_{ss}
THETAX	$\theta_{xx} = \int_0^{\delta}\left(1-\frac{u}{U}\right)\frac{u}{U}\left(1+\frac{z}{r_w}\right)dz$, *axisymmetric definition.*
U/UU	u/U
VEL	velocity
V/U	v/u
V/UU	v/U
W	ω
Z	z

List of Subroutines:

Name	Function
AV	Integration and averaging process.
DATSM	Smoothing of data.
DERIV	Computation of As. & Fs. (Eq.5.9).
DYEDX	Formation of D.E.(5.1).

MRS1	Computation of terms of D.E.(5.1).
RKN	Rung-Kutta method for solving simultaneous D.Es.
RLDIF	Differentiation.
PLINP	Computation of K_1, $\frac{1}{U}\frac{dU}{ds}$, $\frac{1}{U}\frac{dU}{dn}$ & $\tan\alpha$.
SHAB	Solution of algebraic equation.
SIMQ	Solution of linear equations.
SPINT	Interpolation or differentiation on the spline curve.
SPLIC	Determination of spline co-efficients.
STDIV	Equal division of mass flow among annuli.
ZFIN	Determination of new radii, for equal mass flow rate per annulus.

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