NUMERICAL INVESTIGATION OF THREE-DIMENSIONAL FLOW SEPARATION

WIE, YONG-SUN

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Wie, Yong-Sun, Ph.D.

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U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

NUMERICAL INVESTIGATION OF THREE-DIMENSIONAL FLOW SEPARATION

by

YONG-SUN WIE

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ABSTRACT

WIE, YONG-SUN. Numerical Investigation of Three-Dimensional Flow Separation. (Under the direction of Dr. Fred R. DeJamette.)

The steady, three-dimensional laminar and turbulent boundary-layer equations are solved in a streamline coordinate system and in a self-adaptive grid system using Matsuno's finite difference method. Techniques are developed for calculating laminar and turbulent separation for both the incompressible and compressible flow using the boundary-layer equations. Any type (bubble type or free vortex-layer type) of major separation line can be calculated at any angle of attack on ellipsoids of revolution by this boundary layer code. Results are presented for ellipsoids of revolution at angles of attack up to 45 degrees for incompressible flow.

Agreements with other numerical and experimental results are very good for laminar flows. Turbulent flows are also investigated with algebraic turbulence models proposed by Rotta and Cebeci and Smith. Good agreement with experimental results was obtained at small angles of attack but only qualitative agreement was obtained at a high angle of attack for turbulent flow. This boundary layer code can be applied to the general body shapes. Also compressible flow can easily be solved with this method if the inviscid solution is provided.

BIOGRAPHY

Yong-Sun Wie was born Feb 26, 1952, in Mokpo, Korea. He received a Bachelor of Science degree in aeronautical engineering from Seoul National University in 1978. During his undergraduate years, he served in the Korea Army for three years. After graduation, he worked as a engineer at Sam-Sung Precision Industry for three years and as a research engineer at Korea Institute of Machinery and Metal for one and half years until he came to the United States in 1982. He then joined the graduate program of Mechanical and Aerospace Engineering Department at North Carolina State University and received the Master of Mechanical Engineering degree in 1984 under the direction of Dr. Fred R. DeJarnette.

The author is married to the former Miss. Won-Ok Lee and they have a son, Moon-Kyung (John) and a daughter, Eun-Hee (Jane).

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NOMENCLATURE

A , B	major and minor semiaxis length (meters) of ellipsoid of revolution
$\mathcal{A}_j$, $\mathcal{B}_j$, $\mathcal{C}_j$, α_j , $\mathcal{D}_j$	Eq. (5.16)
A^* , B^*	defined in Eq. (4.11)
$\mathcal{A}^*_j$, $\mathcal{B}^*_j$, $\mathcal{C}^*_j$, $\mathcal{D}^*_j$	Eq. (5.18)
A_o , B_o , C_o	defined in Eqs. (3.7) and (3.8)
ap	defined in Eq. (3.4)
a_1 , a_2 , a_3 , a_4	defined in Eqs .(2.27) - (2.2 9)
b_1 , b_2 , b_3 , b_4	defined in Eq. (2.25)
C	defined in Eq. (4.13)
C^*	defined in Eq. (4.14)
c	defined in Eq. (2.54)
c_a	constant coefficient for an adaptive grid method in the η-direction, Eq .(7.18)
E	defined in Eq. (2.53)
E_1	defined in Eq. (3.6)
G_1	defined in Eq. (3.43)
F , G	defined in Eq.(2.53)
f , g	functions defined in Eqs. (2.46) and (2.47)

H	total enthalpy
$\mathcal{H}_j$, $\hbar_j$	defined in Eq. (5.17)
h_1 , h_2	metric coefficients in the x and z coordinates, respectively
IMAX	number of steps in the x-direction
JMAX	number of points across the boundary layer (in the η-direction)
KMAX	number of points in the z-direction where the boundary layer calculations are performed
KMAXF	total number of streamlines
K_1 , K_2	geodesic curvature of the curves $z = const.$ and $x = const.$, respectively, defined in Eq. (2. 8)
L	defined in Eq. (2.31)
M	integer for a nonuniform grid in the z-direction, defined in Eq. (8.1)
Ma	Mach number
m_1 - m_{12}	coefficients, defined in Eq. (2.56) or Eq. (2.70)
N	defined in Eq. (2.77)
p	pressure
p^+	dimensionless pressure gradient, defined in Eq. (2.35)
p_1	defined in Eq. (3.14)
Pr	Prandtl number (laminar)
Pr_t	turbulent Prandtl number

R , θ , ϕ	spherical polar coordinates, Fig. 3
$\mathcal{R}$	gas constant
r	defined in Eq. (3.18) and Fig. 2
Re	Reynolds number, defined in Eq. (2.75)
s	actual distance along the streamline, defined in Eq. (2.45)
T	temperature
t	a measure of anisotropy of turbulence
U , V , W	undisturbed free stream velocity components in the x', y', and z'-directions, respectively, Eqs. (3.9) - (3.11)
u , v , w	velocity components in the x , y , and z-directions, respectively
u^* , v^* , w^*	velocity components in the x*, y*, and z*-directions, respectively
u_e	inviscid velocity component in the streamwise (x) direction = inviscid total velocity, Eq. (2.59)
u_e^* , v_e^* , w_e^*	inviscid velocity components in the x*, y* , and z* -directions, respectively
u_R , u_θ , u_ϕ	inviscid velocity components in the R , θ, and φ -directions, respectively
$u_{x'}$, $u_{y'}$, $u_{z'}$	inviscid velocity components in the x' , y', and z'-directions, respectively
u_τ	defined in Eq. (2.33)

V_∞	undisturbed free stream velocity
w'_z	$\partial w/\partial z$
x, y, z	streamline coordinates, with x oriented in the direction of streamlines, y the outer normal to the surface, and z the direction perpendicular to both previous directions and tangent to the surface. (Fig. 2)
x', y', z'	rectangular coordinates with the origin at the nose (Fig. 2)
x^*, y^*, z^*	rectangular coordinates with the origin at the stagnation point Fig. 5 a)
$\underline{x}, \underline{y}, \underline{z}$	coordinates for an adaptive grid system
y'_s, z'_s	y', and z' coordinates of the stagnation point, respectively.
α	angle of attack (degrees)
β	angle defined in Eq. (10.2.17) and Fig. 5 b)
γ	ratio of specific heat
$\Delta x, \Delta\eta, \Delta z$	grid spacing in the x, η, and z -directions, respectively
Δx_{max}	maximum allowed stepsize in the x- direction
δ	boundary layer thickness
$\delta_\eta, \Delta_\eta, \delta_z$	finite difference operators, defined in Eqs. (5.1) - (5.3)
ε	shperical angle of ε-cone

ε_H	defined in Eq. (2.26)
ε_m	eddy viscosity
η	transformed normal coordinate, defined in Eq. (2.44)
η^*	transformed normal coordinate for the stagnation point solution, defined in Eq. (4.7)
θ	one of spherical polar coordinates, Fig. 3
θ_r	defined in Eq. (10.1.5) and Fig. 5 a)
θ_s	θ at the stagnation point, defined in Eq. (3.47)
λ	defined in Eq. (3.5)
μ	viscosity coefficient
μ_1, μ_2, μ_3	defined in Eq.(2.56) or Eq(2.70)
ν	kinematic viscosity coefficient
ξ	defined in Eqs. (4.6) and (4.7)
ρ	density
τ_{tw}	defined in Eq. (2.36)

ϕ	one of the spherical polar coordinates, Fig. 3
Φ, Ψ	vector potential, defined in Eq. (2.43) or Eq. (2.63) or Eq. (4.6)
ω_j	spring constants (or weight functions) in the η-direction, Eq. (7.18)
ω_k	spring constants (or weight functions) in the z-direction, Eq. (7.20)

Subscript

e	edge of the boundary layer
i	inner region
n	on the body surface
o	outer region
s	stagnation point
w	wall
x	partial differentiation with respect to x ; $\partial/\partial x$
$\underline{x}$	partial differentiation with respect to $\underline{x}$; $\partial/\partial \underline{x}$
z	partial differentiation with respect to z ; $\partial/\partial z$
$\underline{z}$	partial differentiation with respect to $\underline{z}$; $\partial/\partial \underline{z}$
ε	intersection of the ε-cone and the body surface
η	partial differentiation with respect to η ; $\partial/\partial\eta$
$\underline{\eta}$	partial differentiation with respect to $\underline{\eta}$; $\partial/\partial\underline{\eta}$

∞	free stream
$(\ )_{x,y}$	holding x and y constant, etc.

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