

## RANS

$\kappa - \varepsilon$

RANS

( $\kappa - \omega$  RNG  $\kappa - \varepsilon$ )

$\kappa - \varepsilon$

$\kappa - \omega$

RNG  $\kappa - \varepsilon$

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[ ] Medic , Durbin .

[ ] [ ]

STAR\_CD

$v^2 - f$   $\kappa - \varepsilon$

Consigny .[ ]

[ ] Richards

[ ] Arts Camci .

[ ]

[ ] Garg Ameri .[ ]

$\kappa - \omega$  Chien  $\kappa - \varepsilon$  Coakley  $q - \omega$

Baldwin-Lomax

[ ] Azad .

Baldwin-Lomax

[ ] Lakehal .

$\kappa - \varepsilon$

[ ]

:[ ]

$$\frac{\partial \bar{\rho}}{\partial t} + \frac{\partial}{\partial x_i} (\bar{\rho} \tilde{u}_i) = 0 \quad ( )$$

$$\frac{\partial}{\partial t} (\bar{\rho} \tilde{u}_i) + \frac{\partial}{\partial x_j} (\bar{\rho} \tilde{u}_j \tilde{u}_i) = - \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} [\bar{t}_{ji} - \overline{\rho u_j'' u_i''}] \quad ( )$$

$$\frac{\partial}{\partial t} \left[ \bar{\rho} \left( \tilde{e} + \frac{1}{2} \tilde{u}_i \tilde{u}_i \right) + \frac{\overline{\rho u_i'' u_i''}}{2} \right] + \frac{\partial}{\partial x_j} \left[ \bar{\rho} \tilde{u}_j \left( \tilde{h} + \frac{1}{2} \tilde{u}_i \tilde{u}_i \right) + \tilde{u}_j \frac{\overline{\rho u_i'' u_i''}}{2} \right] \quad (1)$$

$$= \frac{\partial}{\partial x_j} \left[ -q_{L_j} - \overline{\rho u_j'' h''} + \overline{t_{ji} u_i''} - \overline{\rho u_j'' \frac{1}{2} u_i'' u_i''} \right] + \frac{\partial}{\partial x_j} \left[ \tilde{u}_i (\bar{t}_{ij} - \overline{\rho u_i'' u_j''}) \right]$$

$$\begin{matrix} t_{ij} & \rho & u & h & e \\ t_{ij} & \cdot & \mu & \zeta & \cdot \end{matrix} \quad [ ]$$

$$t_{ij} = 2\mu s_{ij} + \zeta \frac{\partial u_k}{\partial x_k} \delta_{ij} \quad (2)$$

$$s_{ij} = \frac{1}{2} (u_{i,j} + u_{j,i}) \quad (3)$$

$$\zeta = -\frac{2}{3} \mu s_{ij} \quad (4)$$

$$q_j = -K \frac{\partial T}{\partial x_j} = -\frac{\mu}{Pr_L} \frac{\partial h}{\partial x_j}, \quad Pr_L = \frac{C_p \mu}{K} \quad (5)$$

$$\tau = -\overline{\rho u_i'' u_j''} \quad (6)$$

$$k-\omega \quad RNG \quad k-\epsilon \quad k-\epsilon$$

$$(k) \quad (e)$$

$$\frac{\partial(\rho\kappa)}{\partial t} + \frac{\partial(\rho\kappa u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_T}{\sigma_\kappa} \right) \frac{\partial \kappa}{\partial x_j} \right] + G_\kappa + G_b - \rho\epsilon - Y_M + S_\kappa \quad (7)$$

$$\frac{\partial(\rho\epsilon)}{\partial t} + \frac{\partial(\rho\epsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_T}{\sigma_\epsilon} \right) \frac{\partial \epsilon}{\partial x_j} \right] + C_{1\epsilon} \frac{\epsilon}{K} (G_\kappa + C_{3\epsilon} G_b) - C_{2\epsilon} \rho \frac{\epsilon^2}{K} + S_\epsilon \quad (8)$$

$$\mu_t = C_\mu \rho \frac{k^2}{\epsilon} \quad (9)$$

$$G_b \qquad \qquad \qquad G_k$$

$$Y_M$$

$$S_\varepsilon \quad S_K$$

$$G_k = \mu_T S^2 \qquad \qquad \qquad ( )$$

$$G_b = \beta g_i \frac{\mu_T}{Pr_t} \frac{\partial T}{\partial x_i} \quad , \quad \beta = -\frac{1}{\rho} \left( \frac{\partial \rho}{\partial T} \right)_p \qquad \qquad \qquad ( )$$

$$\qquad \qquad \qquad : \qquad \qquad G_b$$

$$G_b = -g_i \frac{\mu_T}{\rho Pr_t} \frac{\partial T}{\partial x_i} \qquad \qquad \qquad ( )$$

$$\qquad \qquad \qquad : \qquad \qquad Y_M$$

$$Y_M = 2\rho \varepsilon M_t^2 \quad , \quad M_t = \sqrt{\frac{\kappa}{a^2}} \qquad \qquad \qquad ( )$$

$$\qquad \qquad \qquad : \qquad \qquad M_t$$

$$C_{1\varepsilon} = 1.44 \qquad C_{2\varepsilon} = 1.92 \qquad C_\mu = 0.09 \qquad \sigma_K = 1.0 \qquad \sigma_\varepsilon = 1.3$$

$$C_{3\varepsilon} = \tanh \left| \frac{v}{u} \right|$$

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[ ]

RNG  $k-\varepsilon$

$k-\varepsilon$

$\varepsilon$

$k-\varepsilon$

[ ]

$k-\varepsilon$

$k-\varepsilon$

RNG

$\mu_T$

$$\frac{\partial(\rho\kappa)}{\partial t} + \frac{\partial(\rho\kappa u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_T}{\sigma_\kappa} \right) \frac{\partial \kappa}{\partial x_j} \right] + G_\kappa + G_b - \rho\varepsilon - Y_M + S_\kappa \quad ( )$$

$$\frac{\partial(\rho\varepsilon)}{\partial t} + \frac{\partial(\rho\varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \alpha_\varepsilon \mu_{\text{eff}} \frac{\partial \varepsilon}{\partial x_j} \right] + C_{1\varepsilon} \frac{\varepsilon}{\kappa} (G_\kappa + C_{3\varepsilon} G_b) - C_{2\varepsilon} \rho \frac{\varepsilon^2}{\kappa} - R_\varepsilon + S_\varepsilon \quad ( )$$

$$d \left( \frac{\rho^2 \kappa}{\sqrt{\varepsilon \mu}} \right) = 1.72 \frac{\hat{v}}{\sqrt{\hat{v}^3 - 1 + C_v}} d\hat{v} \quad , \quad \hat{v} = \frac{\mu_{\text{eff}}}{\mu} \quad , \quad C_v \approx 100 \quad ( )$$

$$R_\varepsilon = \frac{C_\mu \rho \eta^3 (1 - \eta/\eta_0) \varepsilon^2}{1 + \beta \eta^3} \frac{R_\varepsilon}{\kappa} \quad , \quad \eta_0 = 4.38 \quad , \quad \beta = 0.012 \quad ( )$$

$$\eta = S \frac{\kappa}{\varepsilon} \quad , \quad S = \sqrt{2s_{ij}s_{ij}} \quad ( )$$

$$C_\mu = 0.085 \quad , \quad C_{1\varepsilon} = 1.42 \quad , \quad C_{2\varepsilon} = 1.68 \quad , \quad \alpha_\kappa = \alpha\varepsilon \approx 1.393 \quad , \quad C_{3\varepsilon} = \tanh \left| \frac{v}{u} \right|$$

$$\mu_t = \rho \frac{k}{\omega} \quad ( )$$

$$\frac{\partial}{\partial t} (\rho\kappa) + \frac{\partial}{\partial x_i} (\rho\kappa u_i) = \frac{\partial}{\partial x_j} \left( \Gamma_\kappa \frac{\partial \kappa}{\partial x_j} \right) + G_\kappa - Y_\kappa + S_\kappa \quad ( )$$

$$\frac{\partial}{\partial t} (\rho\omega) + \frac{\partial}{\partial x_i} (\rho\omega u_i) = \frac{\partial}{\partial x_j} \left( \Gamma_\omega \frac{\partial \omega}{\partial x_j} \right) + G_\omega - Y_\omega + S_\omega \quad ( )$$

$$\Gamma_\kappa = \mu + \frac{\mu_T}{\sigma_\kappa} \quad ( )$$

$$\Gamma_\omega = \mu + \frac{\mu_T}{\sigma_\omega} \quad ( )$$

$$: \quad G_\omega \quad ( ) \quad G_\kappa$$

$$G_\omega = \frac{\omega}{\kappa} G_\kappa \quad ( )$$

$$Y_\kappa = \rho \beta^* f_{\beta^*} \kappa \omega \quad ( )$$

$$\beta^* = \beta_i^* [1 + \zeta^* F(M_t)] \quad \beta_{ij}^* = \beta_\infty^* \left( \frac{4/15 + (\text{Re}_t/R_\beta)^4}{1 + (\text{Re}_t/R_\beta)^4} \right) \quad \text{Re}_t = \frac{\rho \kappa}{\mu \omega} \quad ( )$$

$$\begin{cases} 1 & X_k \leq 0 \\ \frac{1+680X_k^2}{1+400X_k^2} & X_k > 0 \end{cases} \quad f_{\beta^*} = \quad x_k = \frac{1}{\omega^3} \cdot \frac{\partial k}{\partial x_j} \cdot \frac{\partial \omega}{\partial x_j} \quad ( )$$

$$Y_\omega = \rho \beta f_\beta \omega^2 \quad ( )$$

$$f_\beta = \frac{1+70X_\omega}{1+80X_\omega} \quad X_\omega = \left| \frac{\Omega_{ij} \Omega_{jk} S_{ki}}{(\beta_\infty^* \omega)^3} \right| \quad \Omega_{ij} = \frac{1}{2} \left( \frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i} \right) \quad ( )$$

$$\beta = \beta_i \left[ 1 - \frac{\beta_i^*}{\beta_i} \zeta^* F(M_t) \right] \quad ( )$$

$$M_t^2 \equiv \frac{2\kappa}{a^2} F(M_t) = \begin{cases} 0 & M_t \leq M_{to} \\ M_t^2 - M_{to}^2 & M_t > M_{to} \end{cases} \quad a = \sqrt{\gamma RT} \quad ( )$$

$$\beta_\infty^* = 0.09 \quad , \quad \beta_i = 0.072 \quad , \quad R_\beta = 8$$

$$M_{to} = 0.25 \quad , \quad \sigma_\kappa = 2.0 \quad , \quad \sigma_\omega = 2.0 \quad , \quad \zeta^* = 1.5$$

$k - \varepsilon \quad \kappa - \omega$

FLUENT 6.2

(time-marching)

[ ]

[ ]

( )

(Cascade)

( )

$$T_C = T_W = 298^\circ K$$

$$S/C = 0.206, 0.237$$

$$S/C = 0.315$$

[ ] [ ]

$$.30 \leq y^+ \leq 300$$

( )

pave

Quad

Map

Quad

RNG  $\kappa - \varepsilon$

$\kappa - \varepsilon$

$\kappa - \omega$

$\kappa - \varepsilon$

RNG  $\kappa - \varepsilon$

$\kappa - \omega$

( )

( )

$\kappa - \omega$

( )

( )

[ ] [ ]

(s)

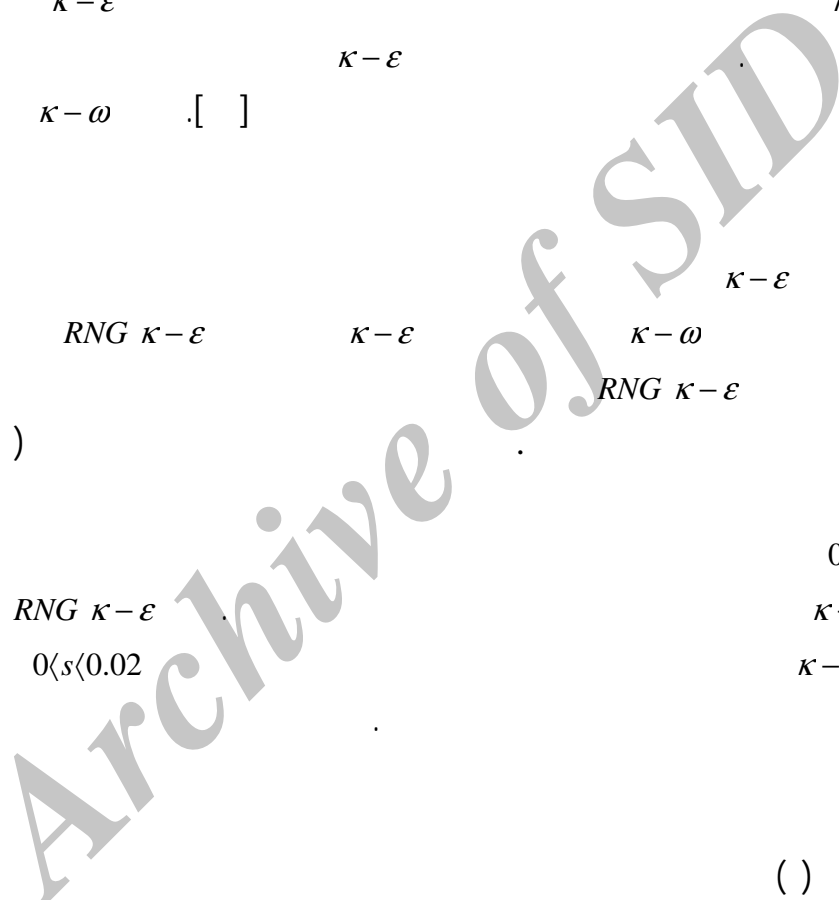
[ ] Richards , Consigny

( ) ( )

$\kappa - \varepsilon$  RNG  $\kappa - \varepsilon$  ( )  
 $\kappa - \omega$   $\kappa - \varepsilon$   $\kappa - \omega$   
 $\kappa - \omega$  [ ]  $\kappa - \omega$

RNG  $\kappa - \varepsilon$   $\kappa - \varepsilon$   $\kappa - \omega$   $\kappa - \varepsilon$   
 ( ) RNG  $\kappa - \varepsilon$

RNG  $\kappa - \varepsilon$   $0 < s < 0.02$   
 $\kappa - \varepsilon$   $0 < s < 0.02$   $\kappa - \varepsilon$   
 $\kappa - \omega$



( ) ( ) / / (m)  
 / (m)

$$m = \frac{u_c \rho_c}{u_\infty \rho_\infty} \quad ( )$$

(s)

$M_{in} = 0.25$   $Re_{c,in} = 8.5 \times 10^5$  ( ) ( )

[ ] Arts Camci .

RNG  $\kappa - \varepsilon$  ( ) ( )



( ) ( )  
 $\kappa - \varepsilon$

( )  
 $S = 0.02 \quad S = 0$

$\kappa - \omega$  .  
 $\kappa - \varepsilon$   
(  $0 < S < 0.02$  ) ( ( ) )  
 $\kappa - \varepsilon$   $\kappa - \omega$   $S = 0.02$   
 $m = /$   $m = /$   $\kappa - \omega$   
 $S = 0$   $\kappa - \omega$  / ( )  
 $S = 0.04$   $S = 0.04$   
/  $\kappa - \omega$   $\kappa - \varepsilon$   
 $S = 0.04$   $S = 0$   
( )  $S = 0.04$   
 $\kappa - \varepsilon$   $m =$   
 $\kappa - \omega$   
 $S = 0.025$   $S = 0$

$\kappa - \omega$

$\kappa - \varepsilon$

)

(h)

(

(h)

(h)

(h)

[ ] Arts Camci

RNG  $\kappa - \varepsilon$

$$\left( \frac{\partial}{\partial x} \left( \frac{\partial \kappa}{\partial x} \right) \right)$$
 $\kappa - \varepsilon$  $\kappa - \omega$  $\kappa - \omega$  $\kappa - \varepsilon$ 

$$RNG \kappa - \varepsilon \quad \kappa - \omega \quad \kappa - \varepsilon$$
 $(\kappa)$ 

$$\left[ \frac{\partial}{\partial x} \left( \frac{\partial \kappa}{\partial x} \right) \right] (\kappa)$$

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:  $c$

:  $C_p$

:  $G_k$

:  $G_\omega$

:  $h$

:  $\kappa$

:  $m$

:  $M_{in}$

:  $M_{is,ex}$

:  $P$

:  $Pr$

:  $Re_{c,in}$

:  $s$

:  $S_{ij}$

:  $T_{in}$

:  $T_{\infty}$

:  $T_w$

:  $Tu$

( ) :  $\tilde{u}$

( ) :  $u''$

:  $u_c$

:  $u_\infty$

:  $Y_k$

: $Y_\omega$

: $\zeta$

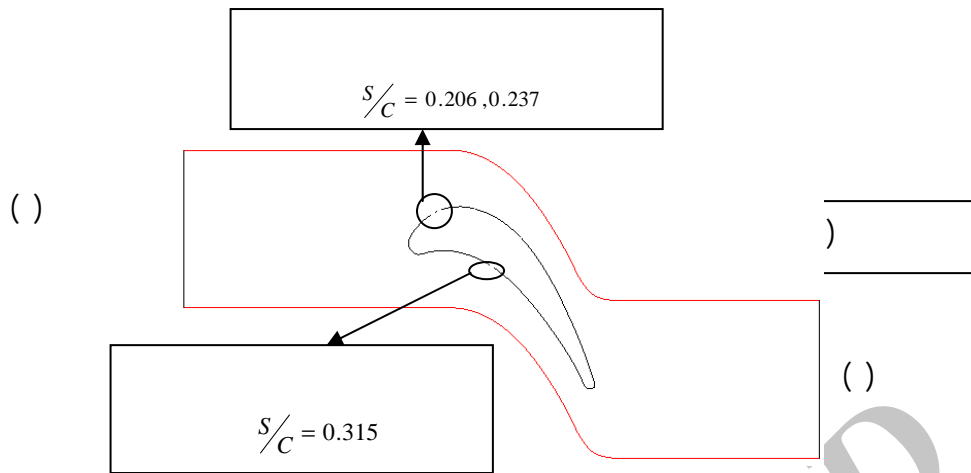
: $\rho$

: $\rho_c$

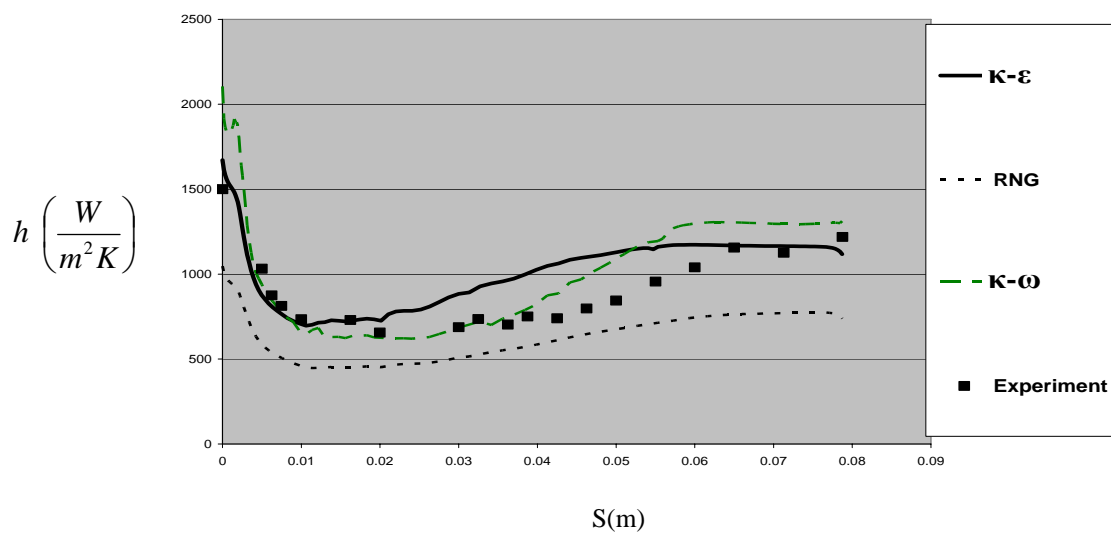
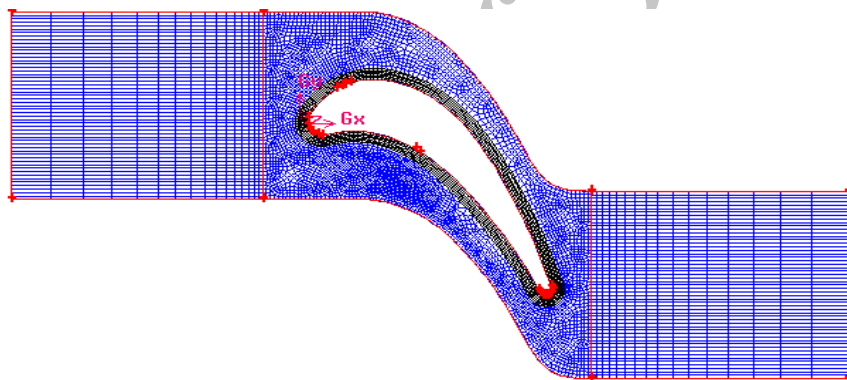
: $\rho_\infty$

	80 mm		30 deg
	100 mm		-69.5 deg
	-38.5 deg	( )	30 deg
	0.670		6.25 mm
Arcsin( / )	21.0 deg		3.0 mm

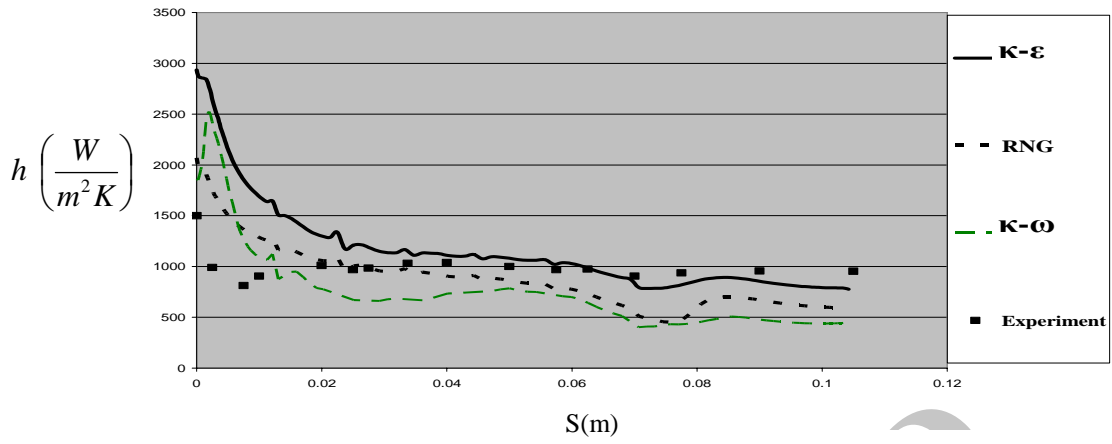
	$M_{in} = 0.25$
( )	$Re_{cin} = 8.5e5$
	$Tu_{in} = 5\%$
	$T_{o\infty} = 409.5^\circ K$
	30 deg
	$M_{ex,is} = 0.92$
	$T_w = 298^\circ k$
	$C_\mu^{3/4} \kappa^{3/2} / \epsilon = 1 \text{ cm}$



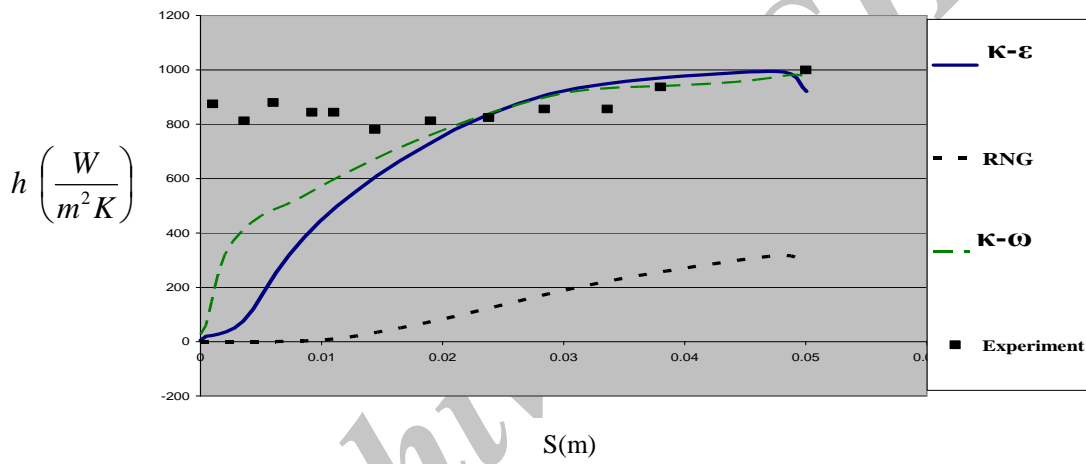
شکل ۱-۱



[ ]

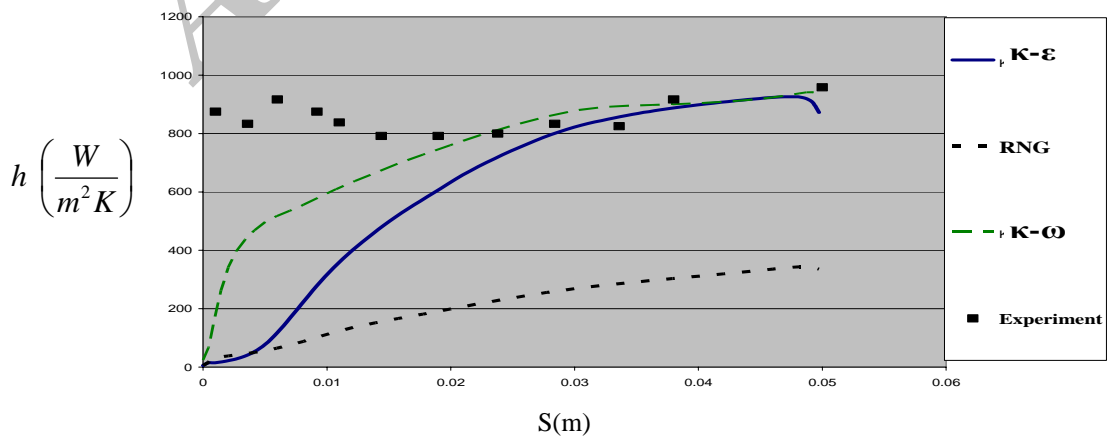


[ ]



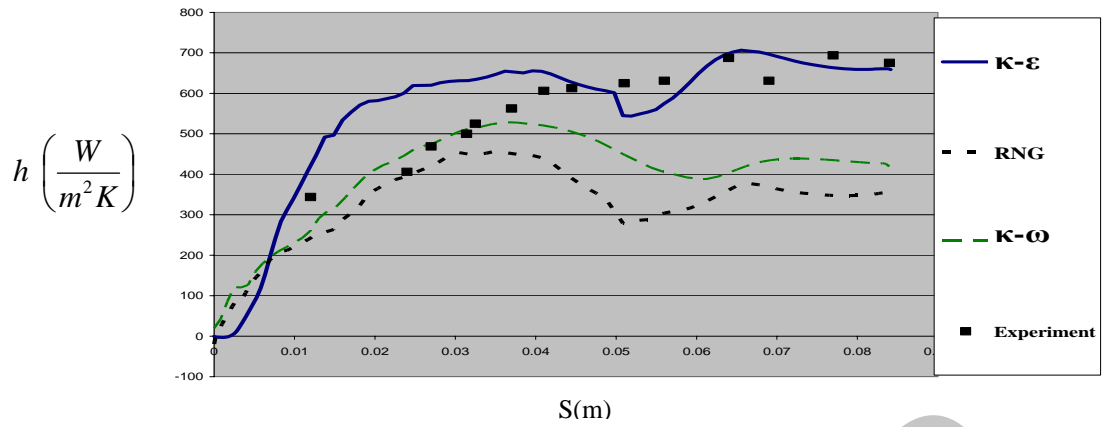
[ ]

$m=1$

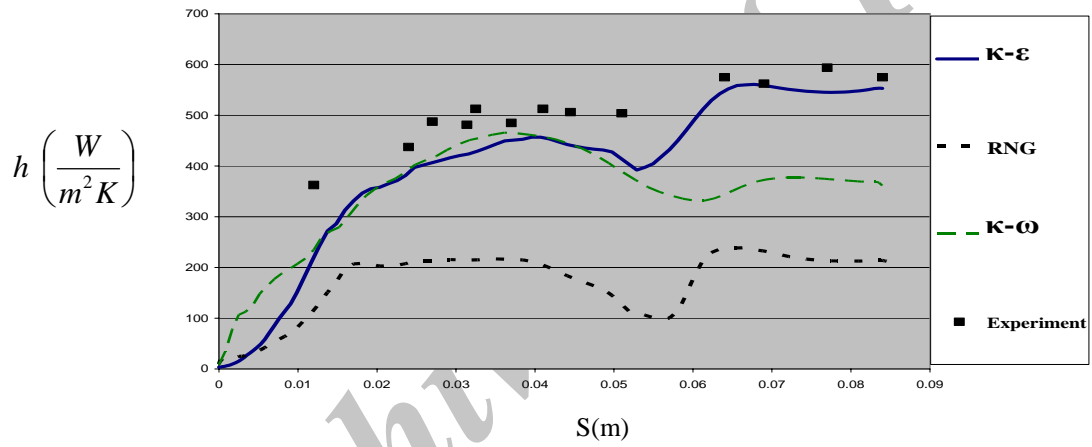


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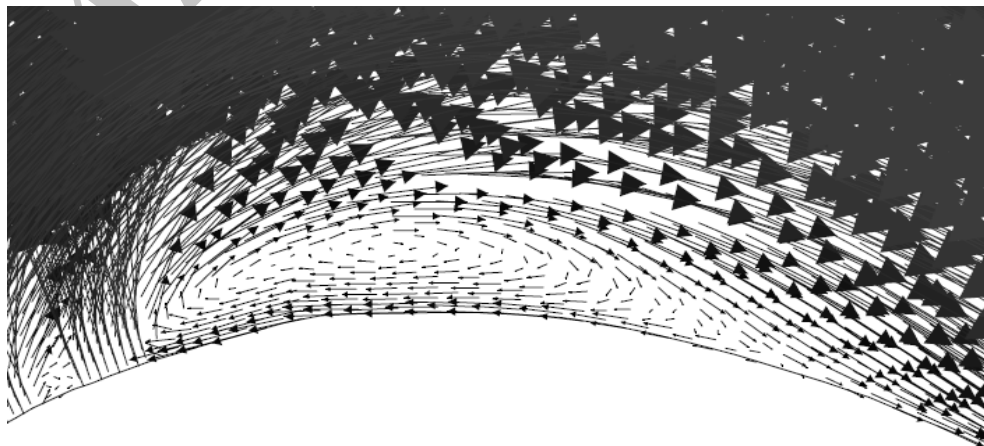
$m=1$

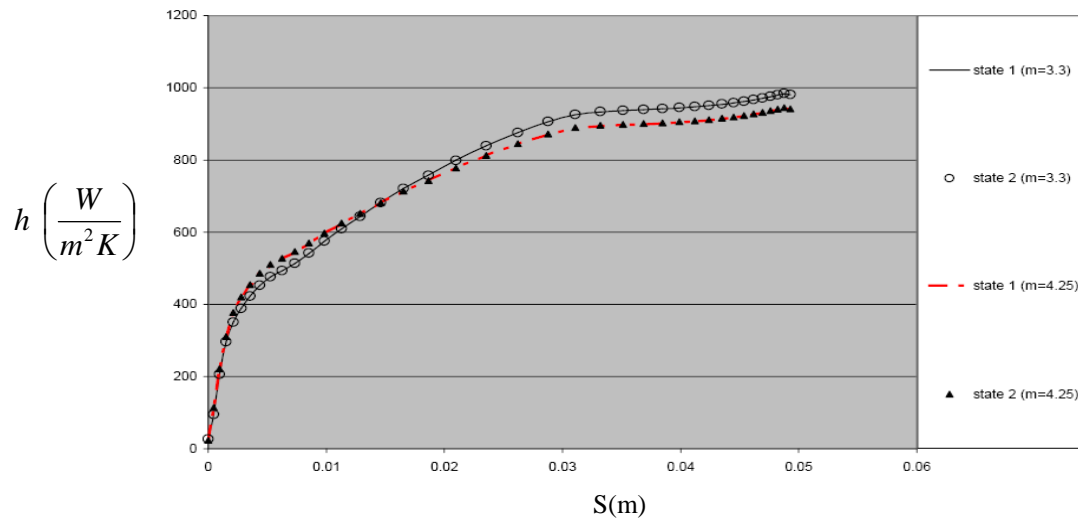
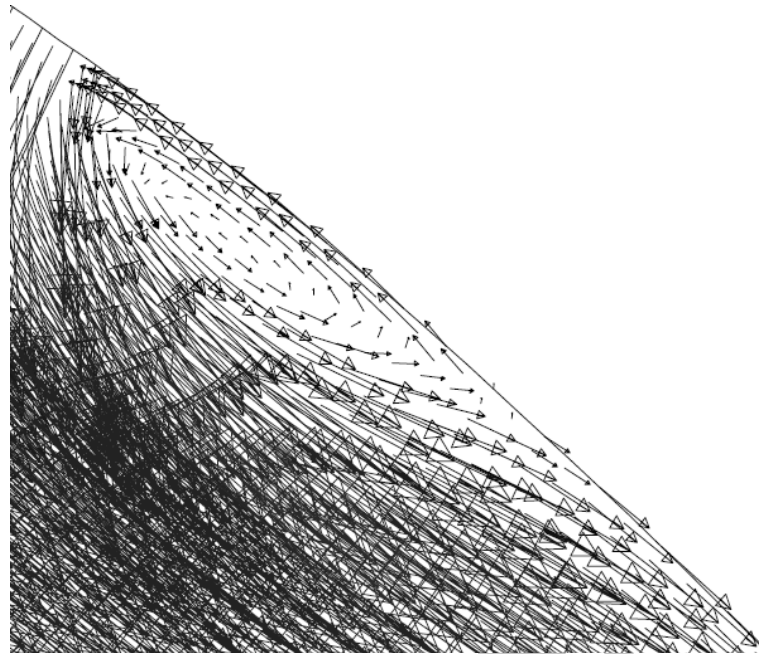


[ ]  $m=1$



[ ]  $m=0.5$





$\kappa - \omega$



## Abstract

In this paper, the application of Reynolds- Averaged Navier-Stokes (RANS) Equations with different turbulence models (standard  $\kappa-\varepsilon$ ,  $\kappa-\varepsilon$  RNG,  $\kappa-\omega$ ) related to the eddy-viscosity in heat transfer and Film-Cooling of the gas turbine rotor blades has been simulated using a Computational Fluid Dynamics (CFD) software. In order to calculate the convection coefficient on surface of gas turbine rotor, prediction of the mentioned turbulence models in two status, with and without Film-Cooling, in different mass flows has also been discussed. The analyzed flow is compressible and Mach numbers in blade inlet and outlet flow are 0.25 and 0.92, respectively. Among these models, in both statuses at the pressure side of the blade  $\kappa-\omega$  model and at the suction side of the blade standard  $\kappa-\varepsilon$  shows the best agreement with experimental data.  $\kappa-\varepsilon$  RNG model could not predict heat transfer on blade surface.

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