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Design and Performance Prediction of Centrifugal Compressor

Mech – Aero 2015
- Aerodynamics -

Oct. 05, 2015

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Institute of Advanced Machines and Design(IAMD)
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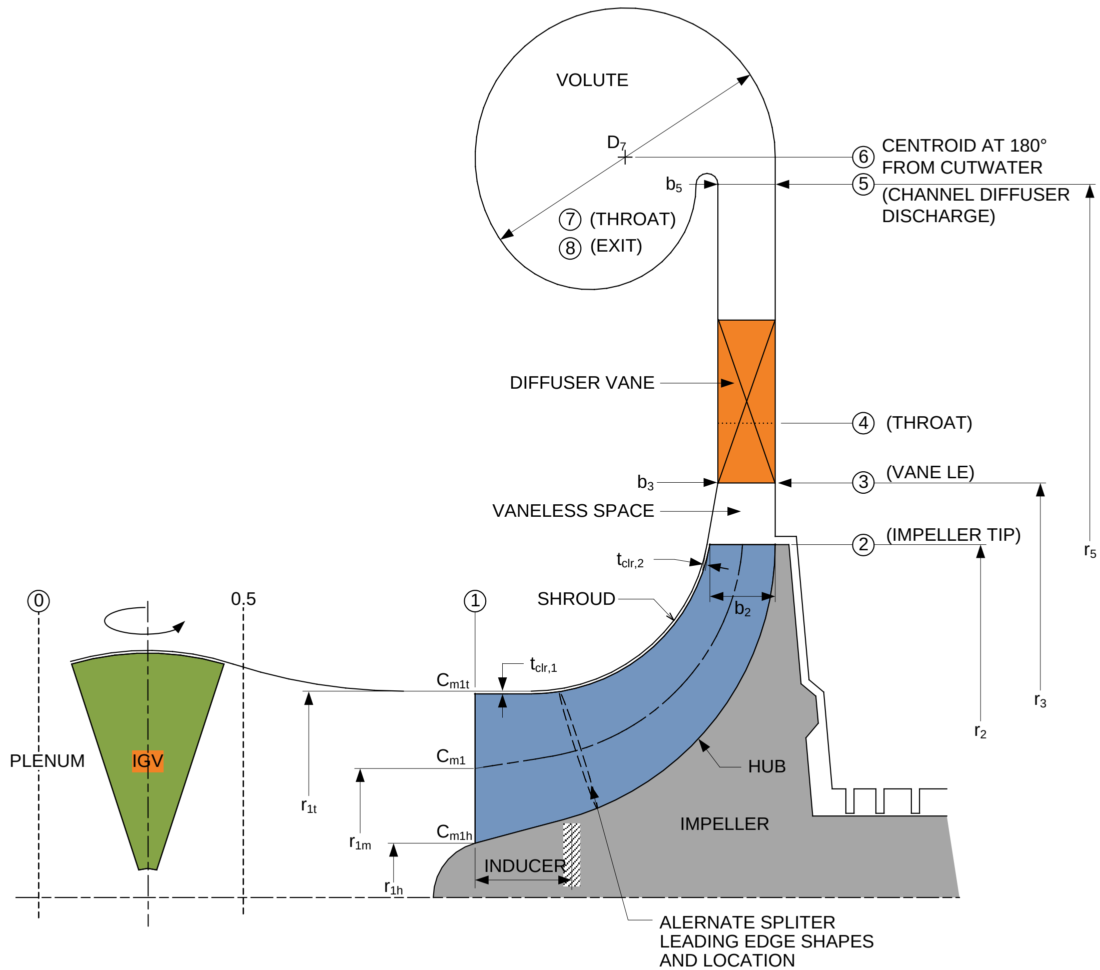
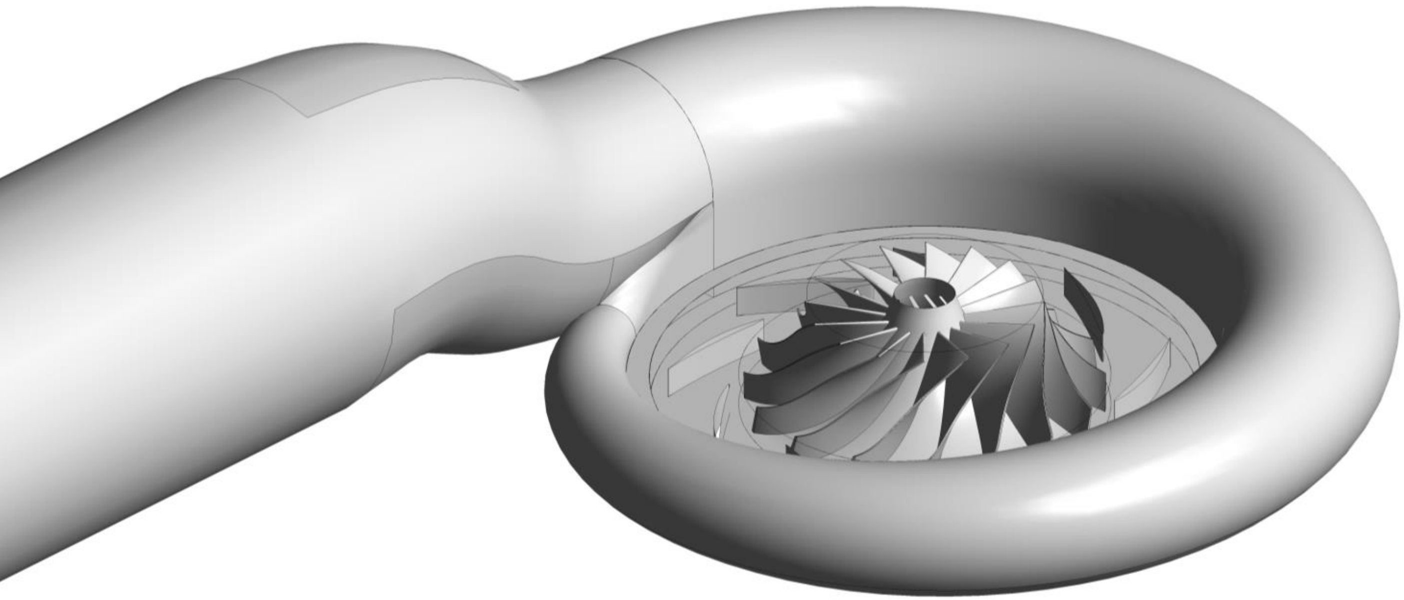
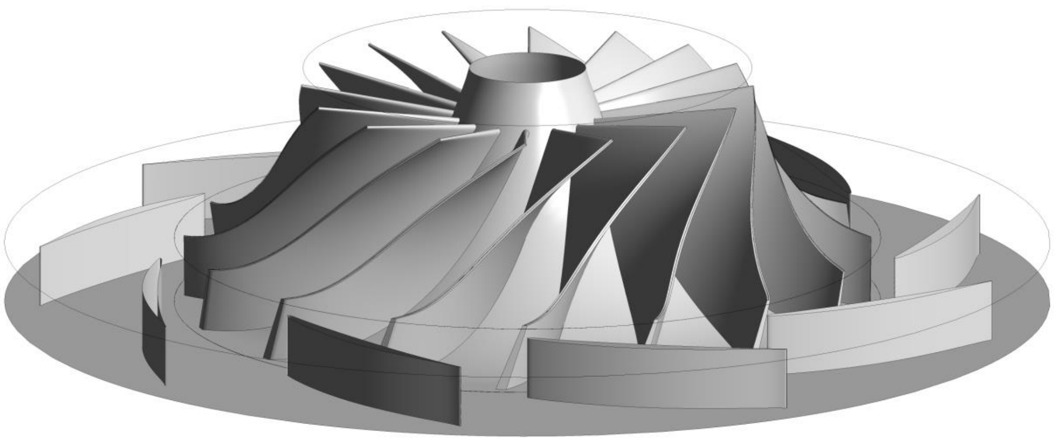
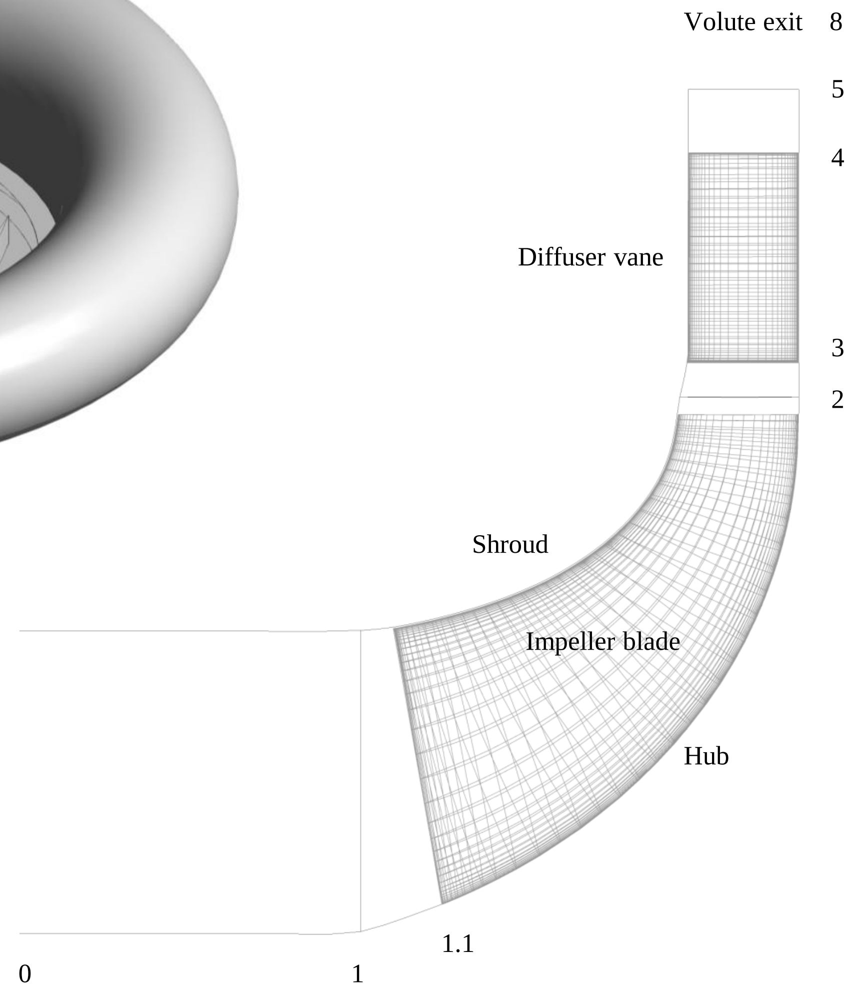
Contents

Centrifugal compressor



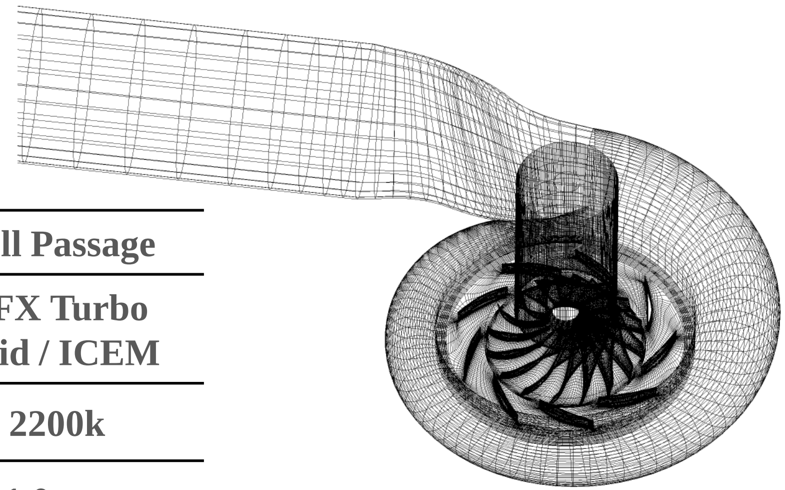


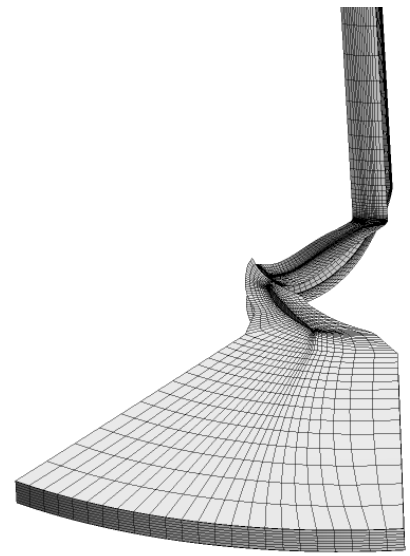



Volute exit
8
5
4
Diffuser vane
3
2
Shroud
Impeller blade
Hub
1.1
0
1

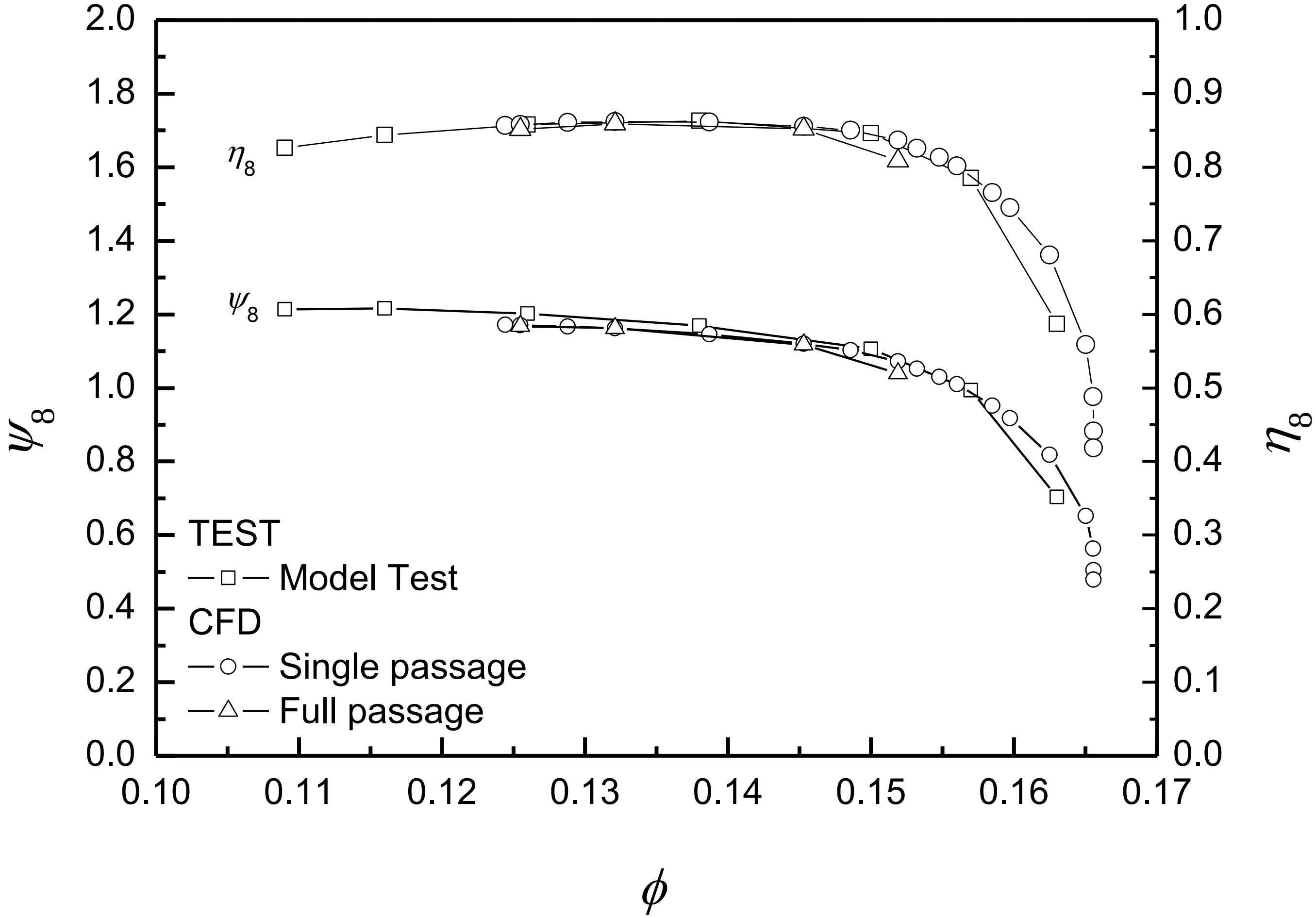
Simulation Condition

Type		Single Passage	Full Passage
Grid	Tool	CFX Turbo Grid	CFX Turbo Grid / ICEM
	Total nodes	120k	2200k
Solver	Tool	ANSYS CFX 11.0	
	Turbulence model	k-ε RANS	
	Simulation type	Steady	
Boundary condition	Inlet	Total pressure Total temperature Flow angle	
	Outlet	Mass flow rate	
	Interface	Mixing plane	

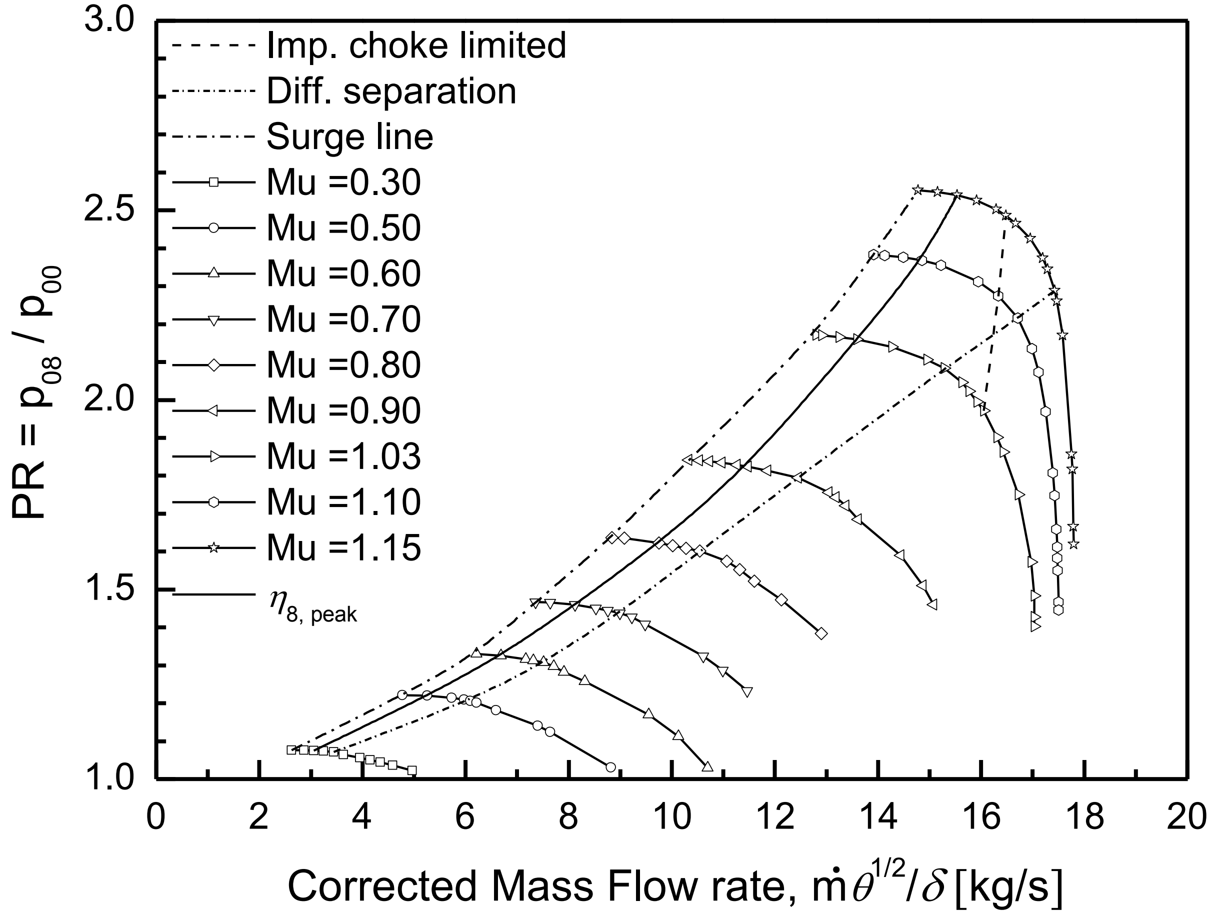




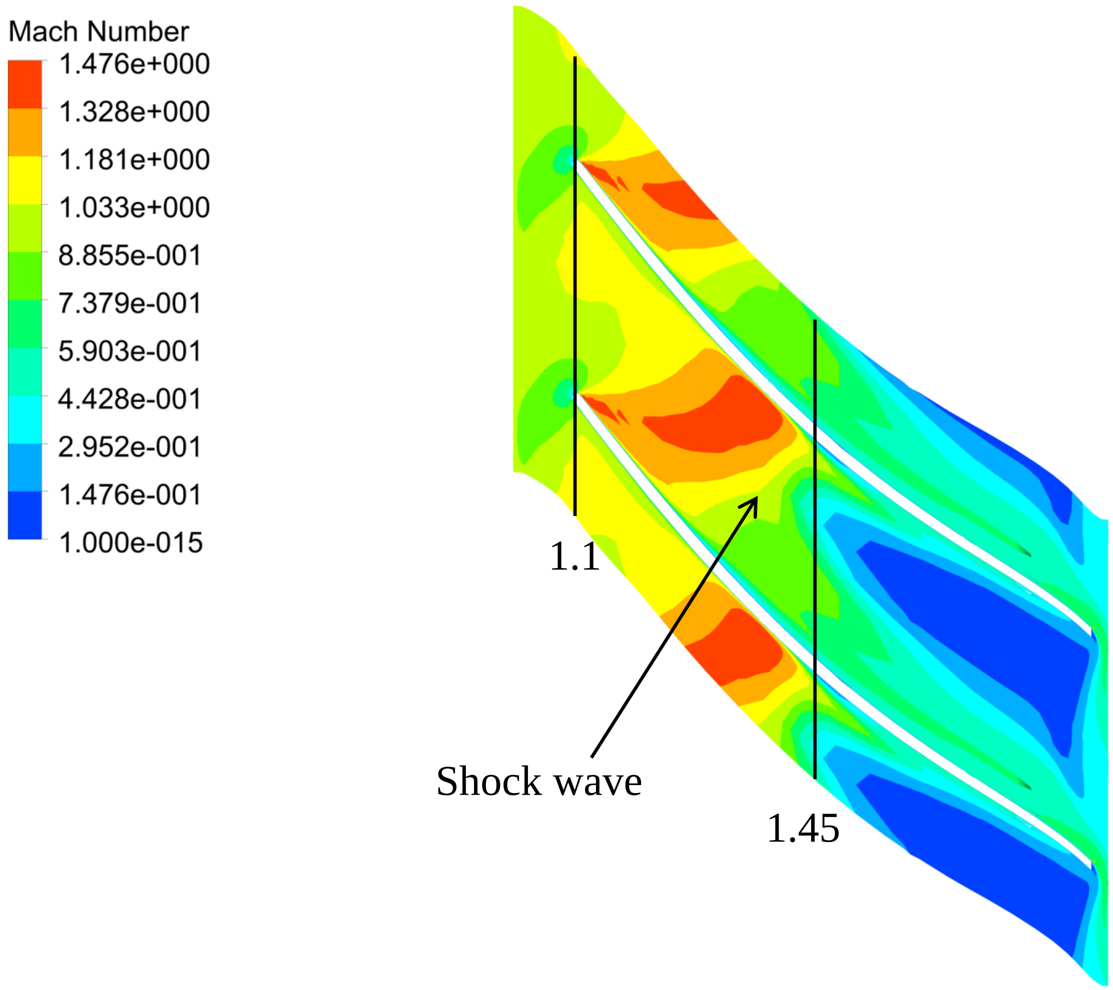
Validation of CFD result



Performance map

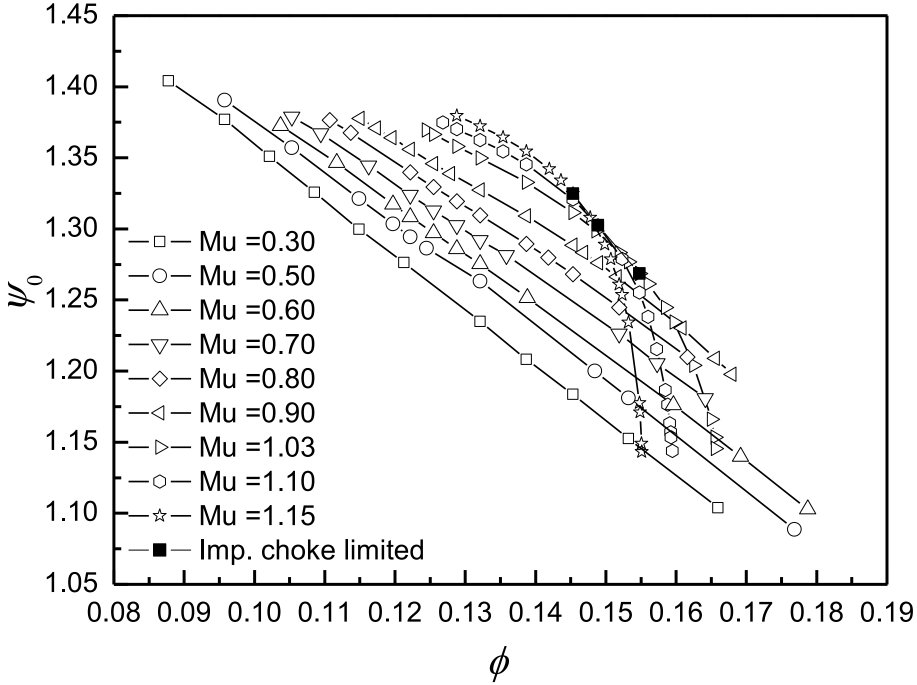


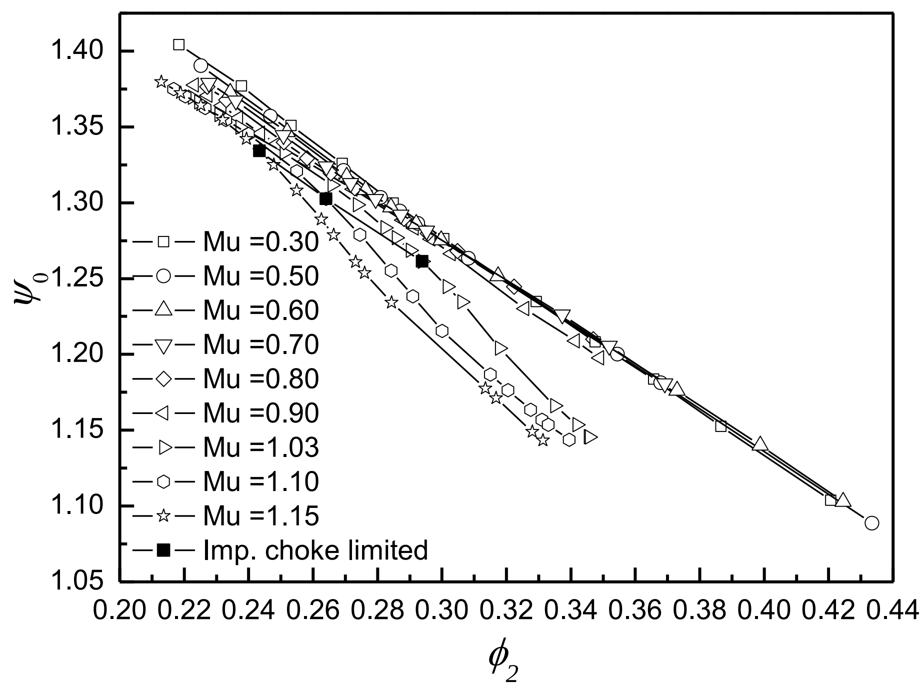
Impeller choking near shroud(0.9span) ; *Mu*=1.10, ϕ=0.158



Impeller Performance ; Work coefficient

$$\psi_0 = \frac{\psi_2}{\eta_2} = 2\frac{\Delta h_{02}}{U_2^{\,2}} = 2\frac{\overline{U_2 c_{\theta 2} - U_1 c_{\theta 1}}^{M}}{U_2^{\,2}} = 2\frac{c_{\theta 2}}{U_2} = 2\frac{C_{p0}\left(T_{02} - T_{01}\right)}{U_2^{\,2}}$$





Flow chart ; Work coefficient Prediction model

$$\frac{\psi_0}{2} = \phi_2 \tan\alpha_2$$

$$\psi_0 = 2\phi_2 \tan\left[k\left(M_u, \phi_2\right)\right]$$

$$\psi_0 = p\left(M_u, \phi_2\right)$$

$$\phi = \frac{\dot{m}}{\rho_{01}\frac{\pi}{4}D_2{}^2U_2} = \frac{\rho_2 A_2 c_2 \cos\alpha_2}{\rho_{01}\frac{\pi}{4}D_2{}^2U_2} = \frac{\rho_2}{\rho_{01}}\frac{\pi D_2 b_2 c_2 \cos\alpha_2}{\frac{\pi}{4}D_2{}^2U_2} = \frac{\rho_2}{\rho_{01}}\frac{4b_2}{D_2}\frac{c_2}{U_2}\cos\alpha_2$$

$$= \frac{2\mu_2 Re_2}{\rho_{01}D_2U_2}\cos\alpha_2 \quad \left[Re_2 = \frac{\rho_2 c_2 2b_2}{\mu_2}\right]$$

$$\alpha_2 = k\left(\phi_2\right);\ fitting\ curve$$

$$Re_2 = l\left(\alpha_2\right);\ fitting\ curve$$

$$\psi_0 = p\left(\phi_2\right) = 2\phi_2 \tan\left\{k\left(\phi_2\right)\right\}$$

$$\phi = q\left(\phi_2\right) = \frac{2\mu_2 l\left(\alpha_2\right)}{\rho_{01}D_2U_2}\cos\alpha_2 = \frac{2\mu_2 l\left(k\left(\phi_2\right)\right)}{\rho_{01}D_2U_2}\cos\left\{k\left(\phi_2\right)\right\}$$

$$\psi_0 = f\left(\phi\right)$$

Flow angle function of flow coefficient at impeller exit

$$0.3 < M_u < 0.8$$

$$Linear\ \ fit\ (x,\ y) = (\phi_2,\ \ \alpha_2)$$

$$\alpha_2 = A + B\phi_2$$

$$parameters\ A, B$$

$$A\ \ : intercept$$

$$B\ \ : slope$$

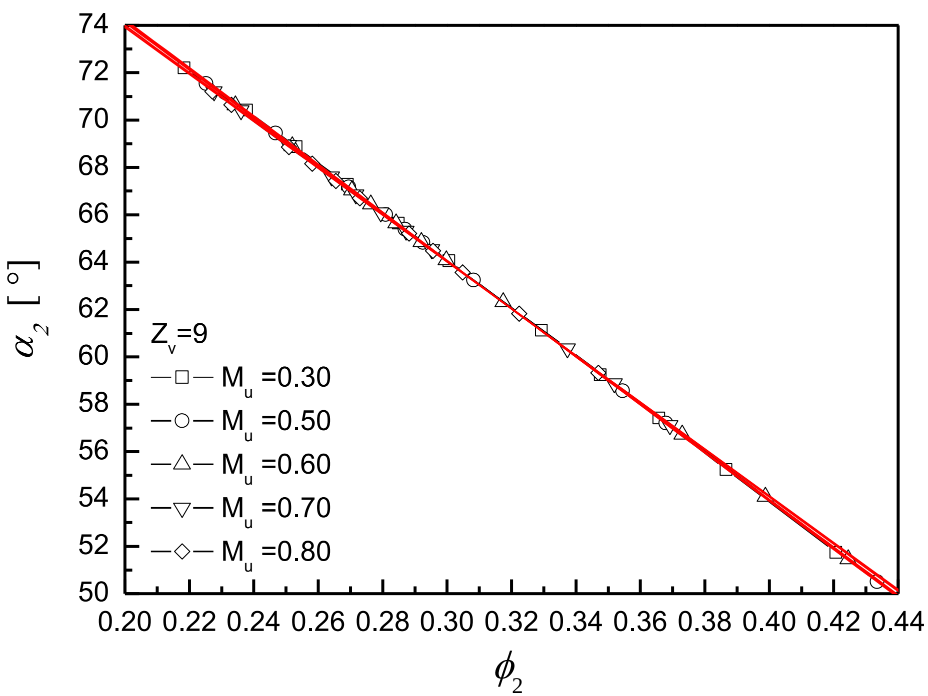
$$Z_v = 9$$

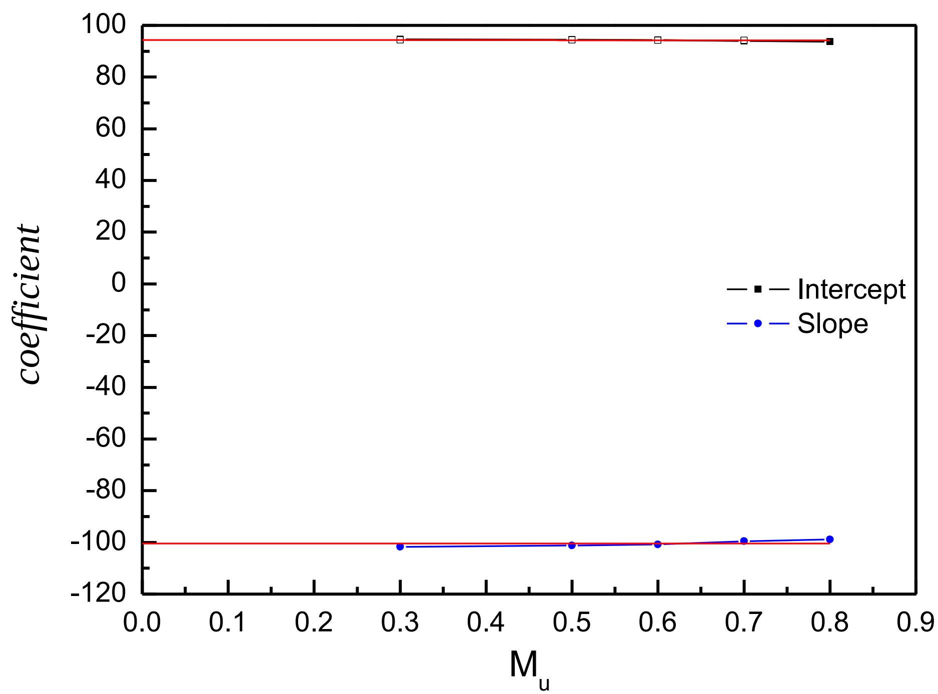
$$\alpha_2 = A(result\ data) + \overline{B}\phi_2$$

$$\begin{bmatrix} Linear\ \ fit\ (x, y) = (M_u, A) \\ A = a + bM_u = 94.37 - 0.197M_u \\ \overline{B} = -100.418 \end{bmatrix}$$

$$\therefore \alpha_2 = a + bM_u + \overline{B}\phi_2$$

$$= 94.37 - 0.197M_u - 100.418\phi_2$$





Flow angle function of flow coefficient at impeller exit

$$0.8 < M_u < 1.2$$

$$Parabola\ \ fit\ (x,\ y) = (\phi_2,\ \ \alpha_2)$$

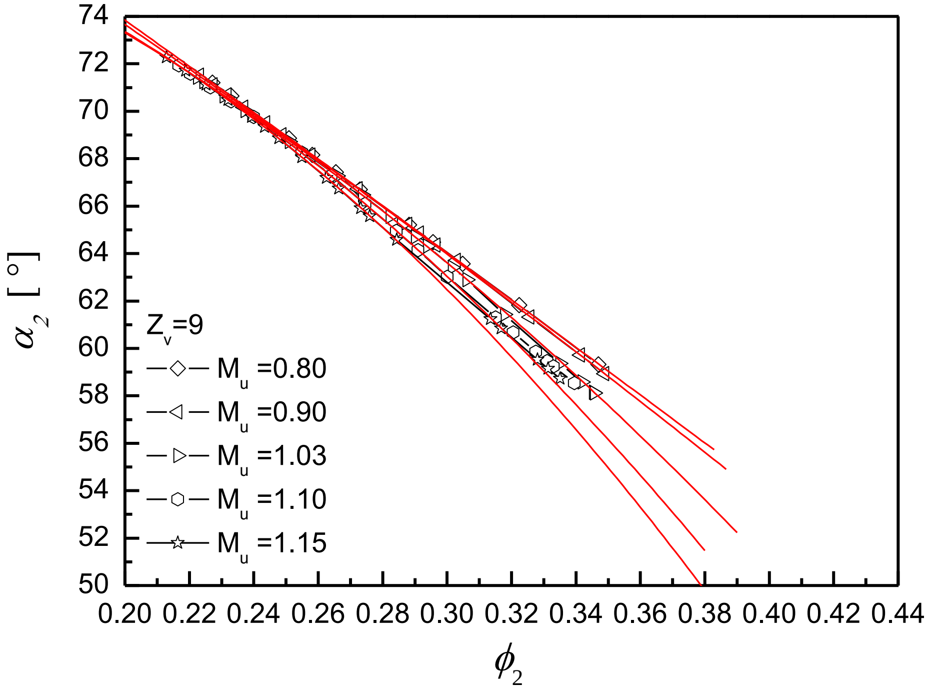
$$\alpha_2 = A + B\phi_2 + C\phi_2{}^2$$

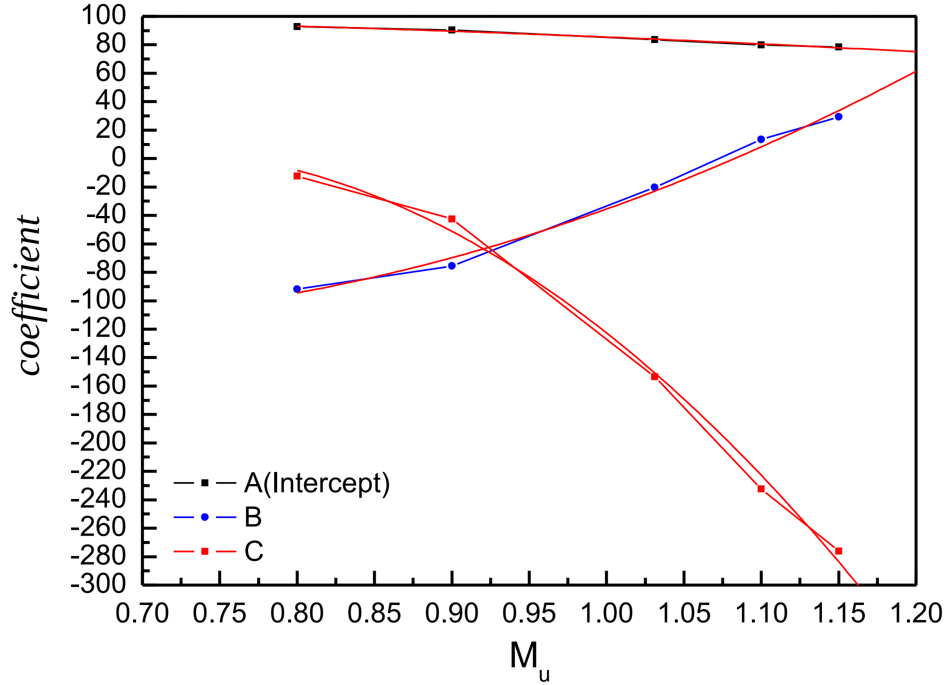
$$parameters\ A, B, C$$

$$Z_v = 9$$

$$\begin{bmatrix} Parabola\ \ fit\ (x, y) \\ A = a + bM_u + cM_u{}^2\ ; a = 97.72, b = 20.325, C = -32.631 \\ B = a + bM_u + cM_u{}^2\ ; a = 48.98, b = -558.8, C = 474.345 \\ C = a + bM_u + cM_u{}^2\ ; a = -696, b = 2004.5, C = -1431.3 \end{bmatrix}$$

$$\therefore \alpha_2 = A(M_u) + B(M_u)\phi_2 + C(M_u)\phi_2{}^2$$





1D equation for predicting work coefficient

$Z_v = 9$

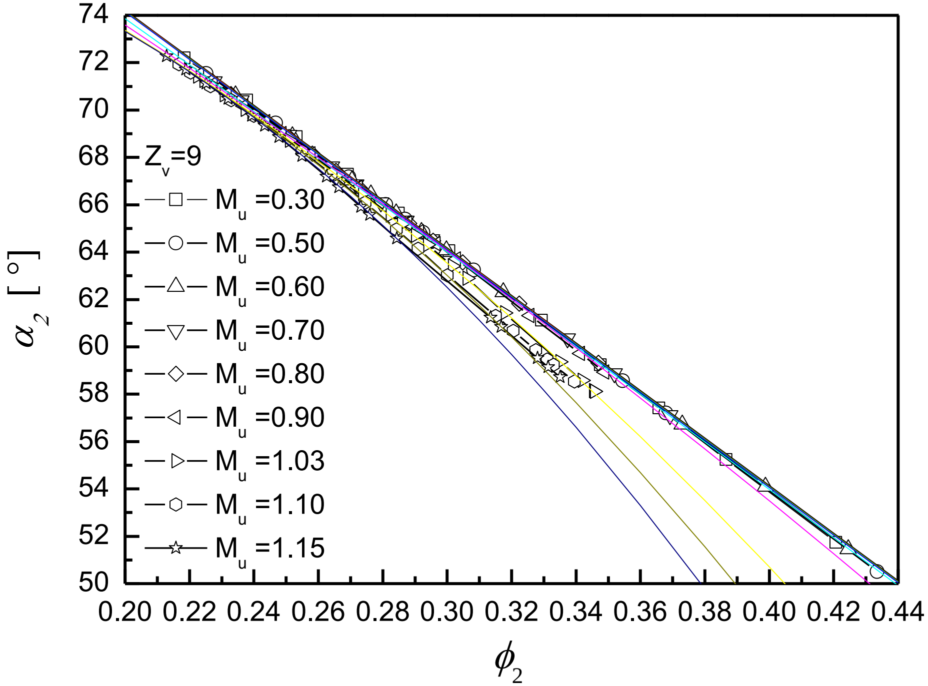
$$\alpha_2 = k(M_u,\phi_2)\begin{cases}\alpha_2 = a + bM_u + \overline{B}(M_u)\phi_2 \\ \quad = 94.37 - 0.197M_u - 100.418\phi_2 \quad ; \quad 0.3 < M_u < 0.8 \\ \alpha_2 = A(M_u) + B(M_u)\phi_2 + C(M_u)\phi_2^{\,2} \quad ; \quad 0.8 < M_u < 1.2\end{cases}$$

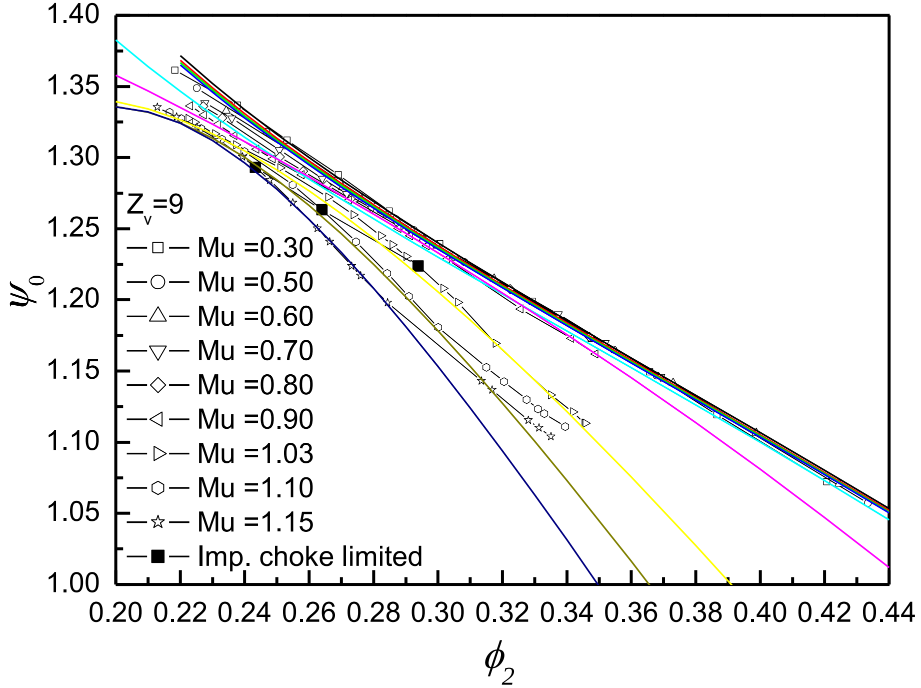
$$\frac{\psi_0}{2} = \phi_2 \tan\alpha_2$$

$$\psi_0 = 2\phi_2 \tan\left[k(M_u,\phi_2)\right]$$

$$\psi_0 = p(M_u,\phi_2)$$

$$\begin{bmatrix} Parabola\ \ fit\ (x,y) \\ A = a + bM_u + cM_u^{\,2}\ ; a = 97.72, b = 20.325, C = -32.631 \\ B = a + bM_u + cM_u^{\,2}\ ; a = 48.98, b = -558.8, C = 474.345 \\ C = a + bM_u + cM_u^{\,2}\ ; a = -696, b = 2004.5, C = -1431.3 \end{bmatrix}$$





1D equation for predicting work coefficient

$Z_v = 12$

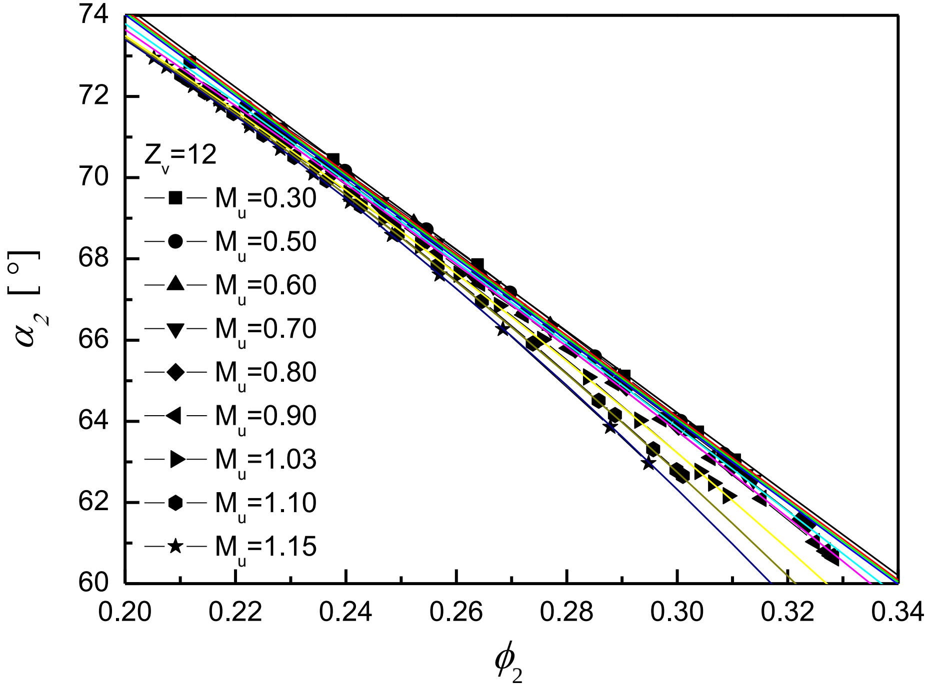
$$\alpha_2 = k(M_u, \phi_2) \begin{cases} \alpha_2 = a + bM_u + \overline{B}(M_u)\phi_2 \\ \quad = 94.45 - 0.546M_u - 100.242\phi_2 \quad ; \quad 0.3 < M_u < 0.8 \\ \alpha_2 = A(M_u) + B(M_u)\phi_2 + C(M_u)\phi_2^{\,2} \quad ; \quad 0.8 < M_u < 1.2 \end{cases}$$

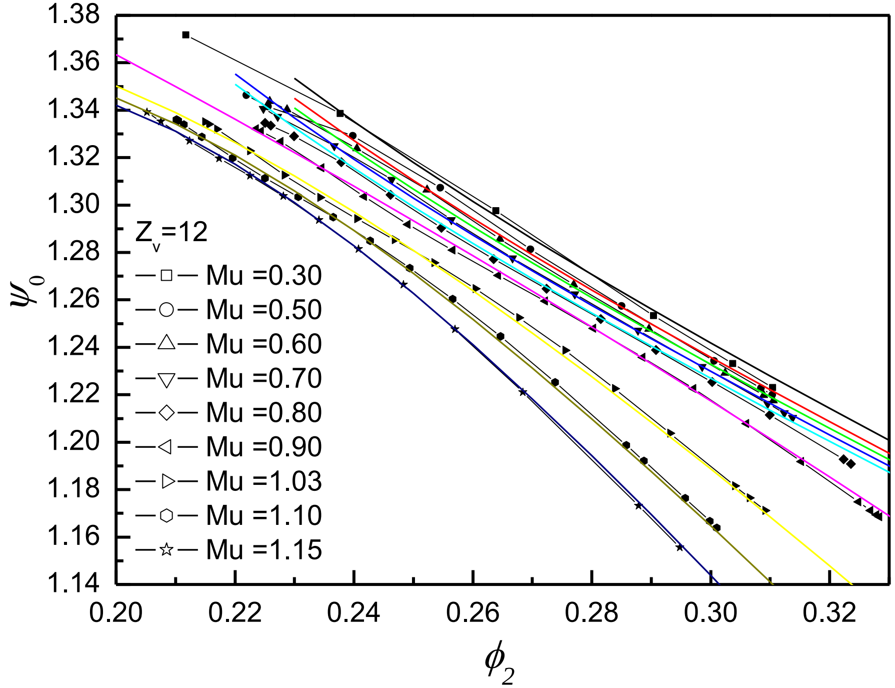
$$\frac{\psi_0}{2} = \phi_2 \tan\alpha_2$$

$$\psi_0 = 2\phi_2 \tan\left[k(M_u, \phi_2)\right]$$

$$\psi_0 = p(M_u, \phi_2)$$

$$\begin{bmatrix} Parabola\ \ fit\ (x, y) \\ A = a + bM_u + cM_u^{\,2}\ ; a = 85.668, b = 29.443, C = -27.849 \\ B = a + bM_u + cM_u^{\,2}\ ; a = 59.662, b = -449.97, C = 343.48 \\ C = a + bM_u + cM_u^{\,2}\ ; a = -541.7, b = 1419.9, C = -987.37 \end{bmatrix}$$





Reynolds number function of flow angle at impeller exit

$0.3 < M_u < 0.8$

$Linear\ \ fit\ (x,\ y) = (\alpha_2,\ Re_2)$

$Re_2 = A + B\alpha_2$

$parameters\ A, B$

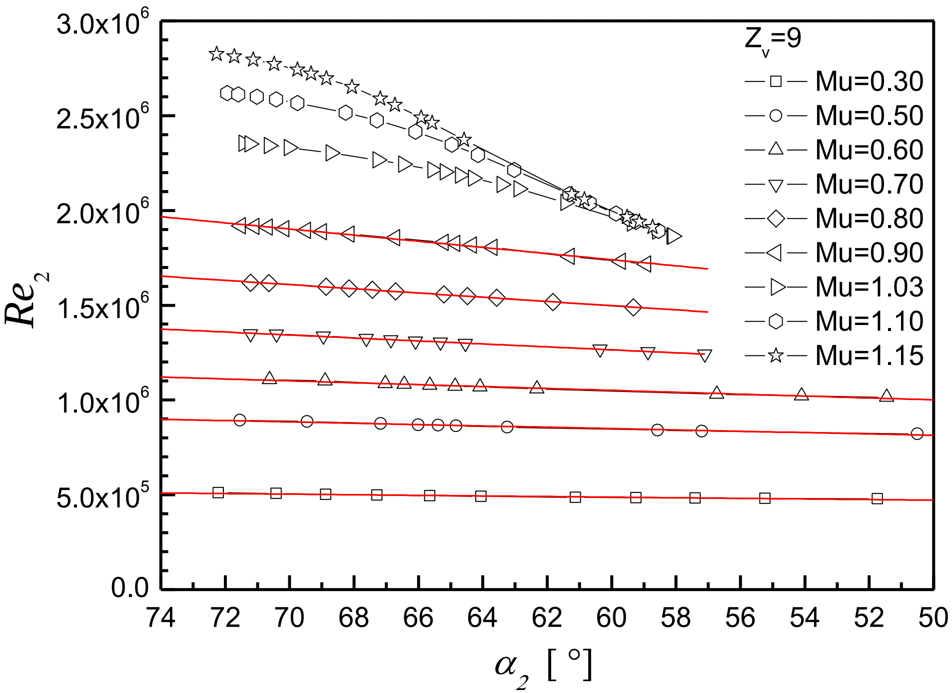
$A\ :\ intercept$

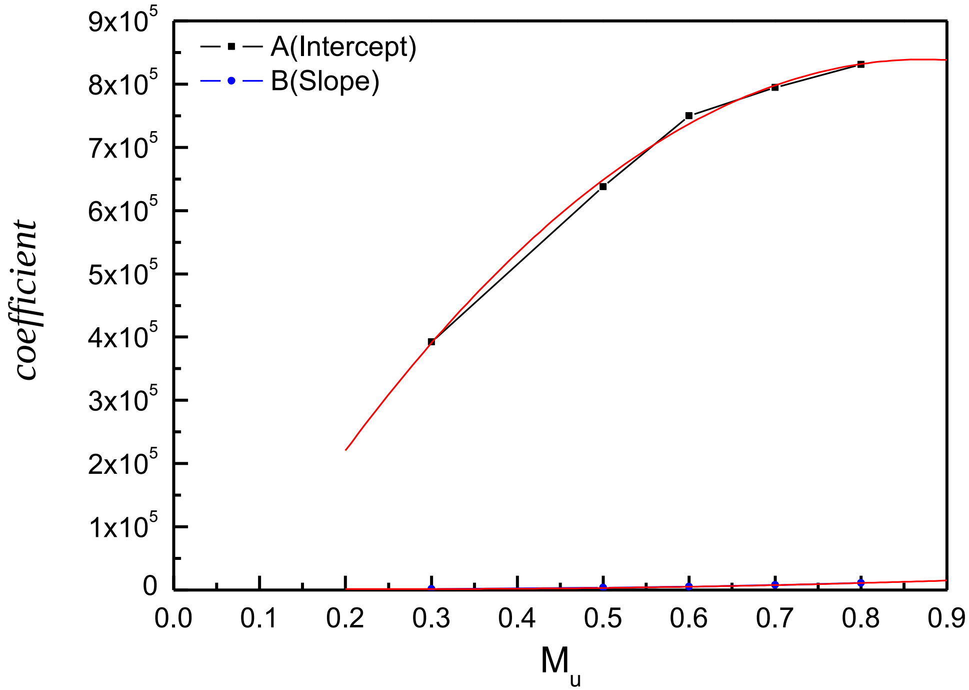
$B\ :\ slope$

$Z_v = 9$

$$\begin{bmatrix} Parabola\ \ fit\ (x, y) \\ A = a + bM_u + cM_u{}^2\ ;\ a = -2.01E+5, b = 2.38E+6, C = -1.36E+6 \\ B = a + bM_u + cM_u{}^2\ ;\ a = 4.254E+3, b = -1.91E+4, C = 3.46E+4 \end{bmatrix}$$

$\therefore Re_2 = A(M_u) + B(M_u)\alpha_2$





Reynolds number function of flow angle at impeller exit

$0.8 < M_u < 1.2$

$Parabola\ \ fit\ (x,\ y) = (\alpha_2,\ \ Re_2)$

$Re_2 = A + B\alpha_2 + C{\alpha_2}^2$

$parameters\ A, B, C$

$Z_v = 9$

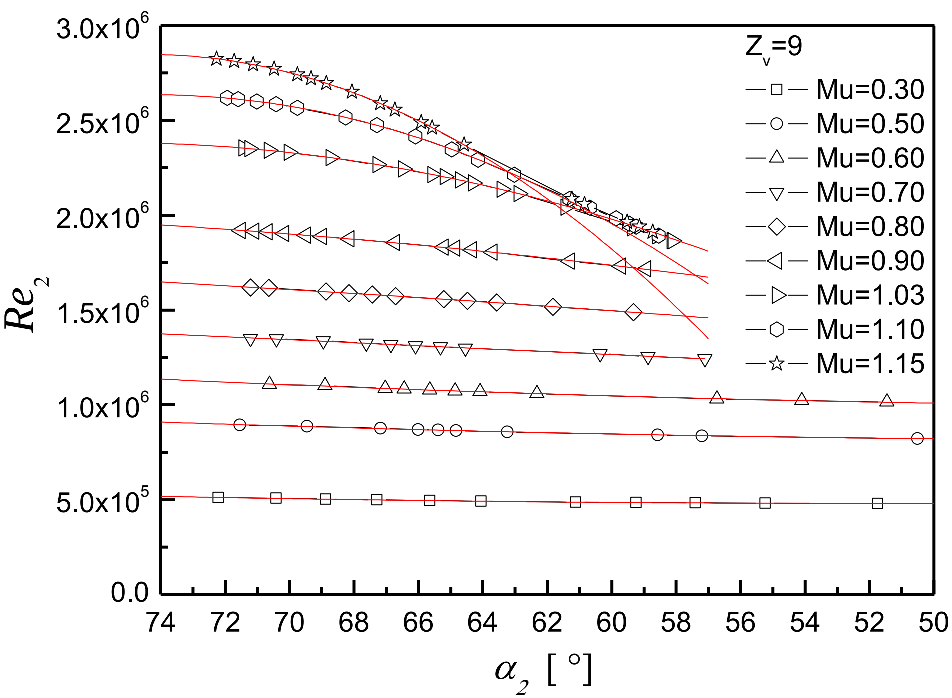
$determine\ A, B, C\ \ from\ 3\ point\ of\ \ test\ or\ CFD$

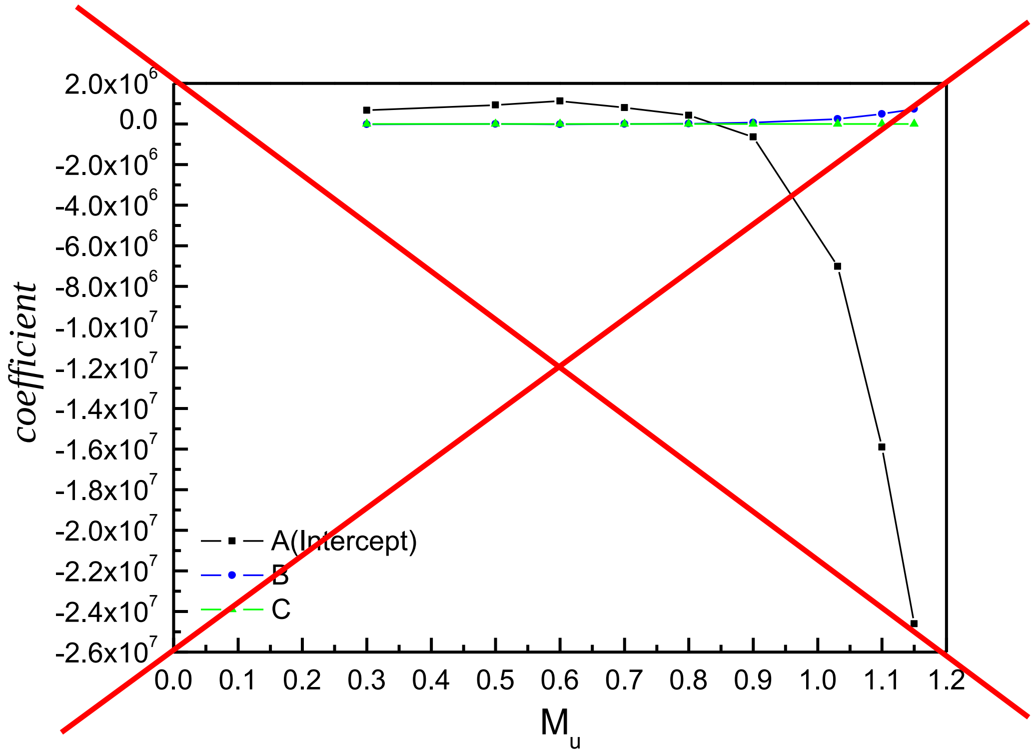
$\because\ all\ curves\ are\ shaped\ \ parabola\ \ fit$

$(\alpha_2,\ \ Re_2)_1, (\alpha_2,\ \ Re_2)_2, (\alpha_2,\ \ Re_2)_3$

$Re_2 = A + B\alpha_2 + C{\alpha_2}^2$

Mu	A(Intercept)	B	C
0.8	428304.9	23436.26	−94.0204
0.9	−6.42E+05	59452.49	−330.27
1.03113249	−7.01E+06	247965.3	−1636.95
1.1	−1.59E+07	500285.9	−3371.06
1.15	−2.46E+07	737054.4	−4953.38





Reynolds number function of flow angle at impeller exit

$Z_v = 9$

$$Re_2 = l(M_u, \alpha_2)\begin{cases} Re_2 = A(M_u) + B(M_u)\alpha_2 & ;\quad 0.3 < M_u < 0.8 \\ Re_2 = A + B\alpha_2 + C\alpha_2^{\,2} & ;\quad 0.8 < M_u < 1.2 \end{cases}$$

$Parabola\ fit\,(x, y)\quad ;\quad 0.3 < M_u < 0.8$

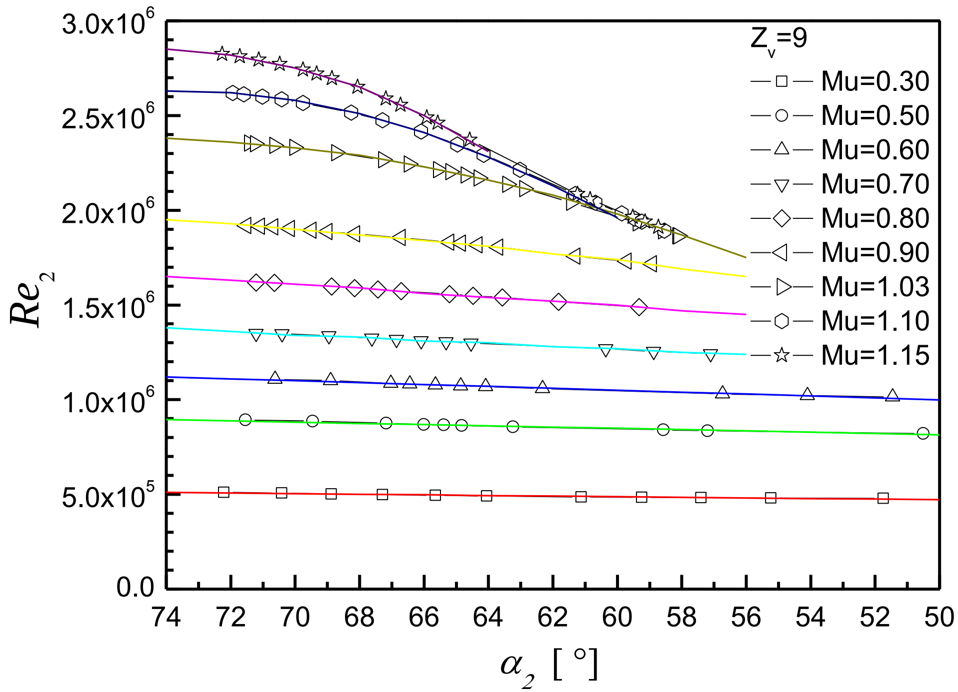
$A = a + bM_u + cM_u^{\,2}\ ;\ a = -2.01E+5, b = 2.38E+6, C = -1.36E+6$

$B = a + bM_u + cM_u^{\,2}\ ;\ a = 4.254E+3, b = -1.91E+4, C = 3.46E+4$

A, B, C are determined by 3 data of test or CFD $;\quad 0.8 < M_u < 1.2$

$(\alpha_2,\ Re_2)_1, (\alpha_2,\ Re_2)_2, (\alpha_2,\ Re_2)_3$

$Re_2 = A + B\alpha_2 + C\alpha_2^{\,2}$



Flow coefficient correlation & Prediction of work coefficient

$$\phi = \frac{\dot m}{\rho_{01}\frac{\pi}{4}D_2^{\,2}U_2} = \frac{\rho_2 A_2 c_2\cos\alpha_2}{\rho_{01}\frac{\pi}{4}D_2^{\,2}U_2} = \frac{\rho_2}{\rho_{01}}\frac{\pi D_2 b_2 c_2\cos\alpha_2}{\frac{\pi}{4}D_2^{\,2}U_2} = \frac{\rho_2}{\rho_{01}}\frac{4b_2}{D_2}\frac{c_2}{U_2}\cos\alpha_2$$

$$= \frac{2\mu_2 Re_2}{\rho_{01}D_2U_2}\cos\alpha_2 \quad \left[Re_2 = \frac{\rho_2 c_2 2b_2}{\mu_2} = l(\alpha_2) = l(k(\phi_2))\right]$$

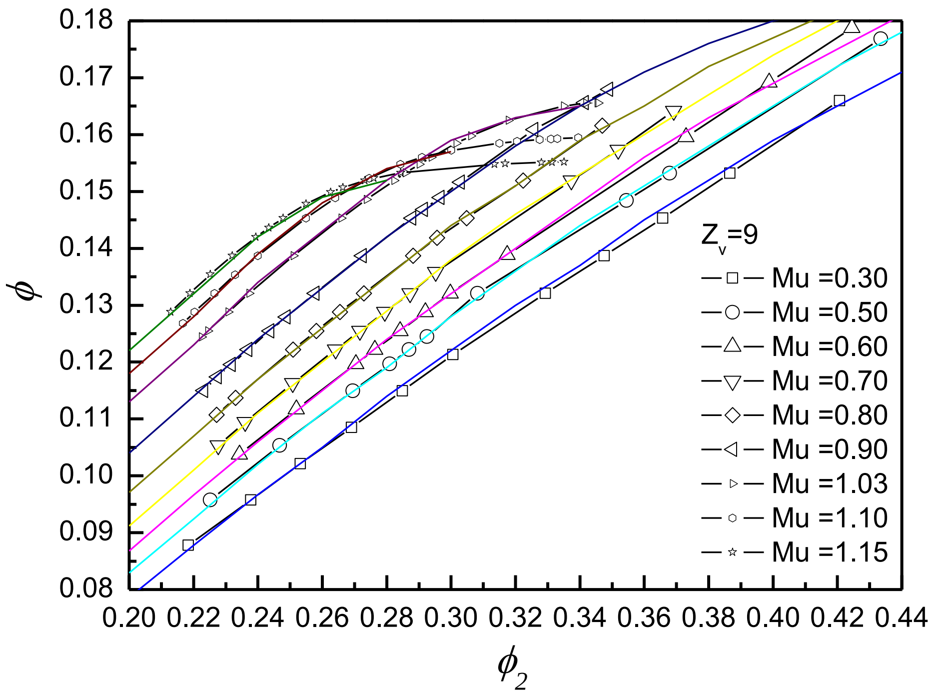
$$= \frac{2\mu_2 l(k(\phi_2))}{\rho_{01}D_2U_2}\cos\{k(\phi_2)\}$$

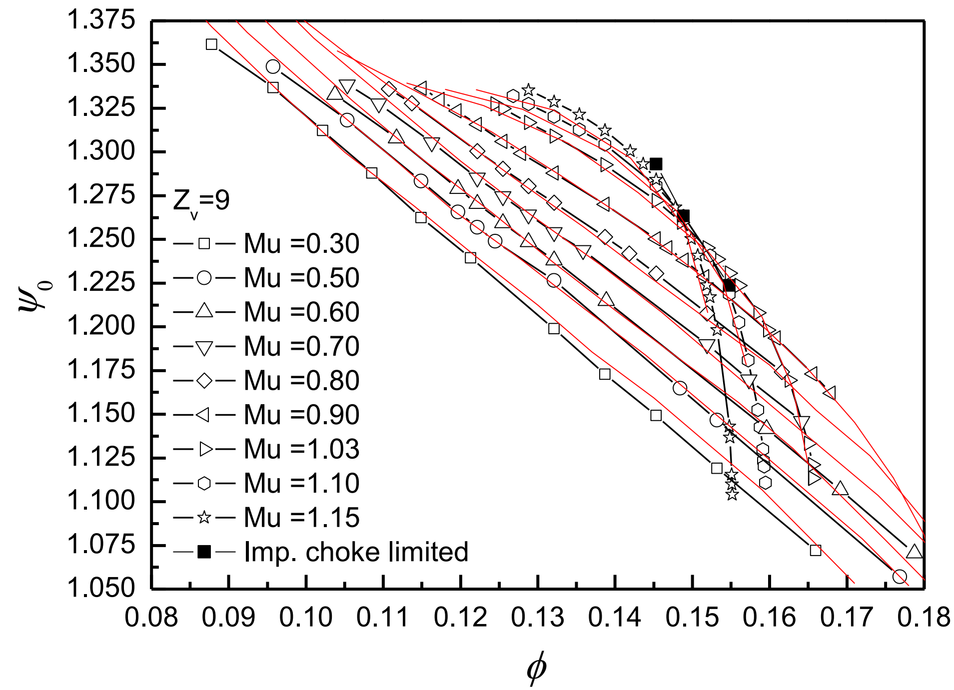
$$= q(\phi_2)$$

$$\frac{\psi_0}{2} = \phi_2\tan\alpha_2$$

$$\psi_0 = 2\phi_2\tan\{k(\phi_2)\}$$

$$\psi_0 = p(\phi_2) = p(q^{-1}(\phi)) = f(\phi)$$





Flow coefficient correlation & Prediction of work coefficient

$$\phi = \frac{\dot{m}}{\rho_{01}\frac{\pi}{4}D_2^{\,2}U_2} = \frac{\rho_2 A_2 c_2 \cos\alpha_2}{\rho_{01}\frac{\pi}{4}D_2^{\,2}U_2} = \frac{\rho_2}{\rho_{01}}\frac{\pi D_2 b_2 c_2 \cos\alpha_2}{\frac{\pi}{4}D_2^{\,2}U_2} = \frac{\rho_2}{\rho_{01}}\frac{4b_2}{D_2}\frac{c_2}{U_2}\cos\alpha_2$$

$$= \frac{2\mu_2 Re_2}{\rho_{01}D_2U_2}\cos\alpha_2 \quad \left[Re_2 = \frac{\rho_2 c_2 2b_2}{\mu_2} = l(\alpha_2) = l(k(\phi_2))\right]$$

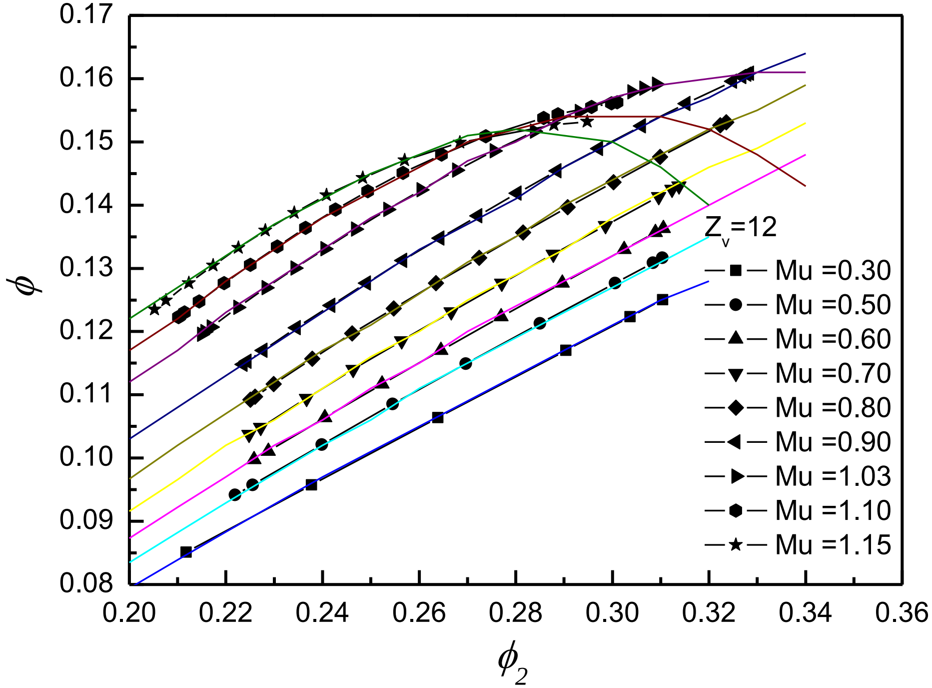
$$= \frac{2\mu_2 l(k(\phi_2))}{\rho_{01}D_2U_2}\cos\{k(\phi_2)\}$$

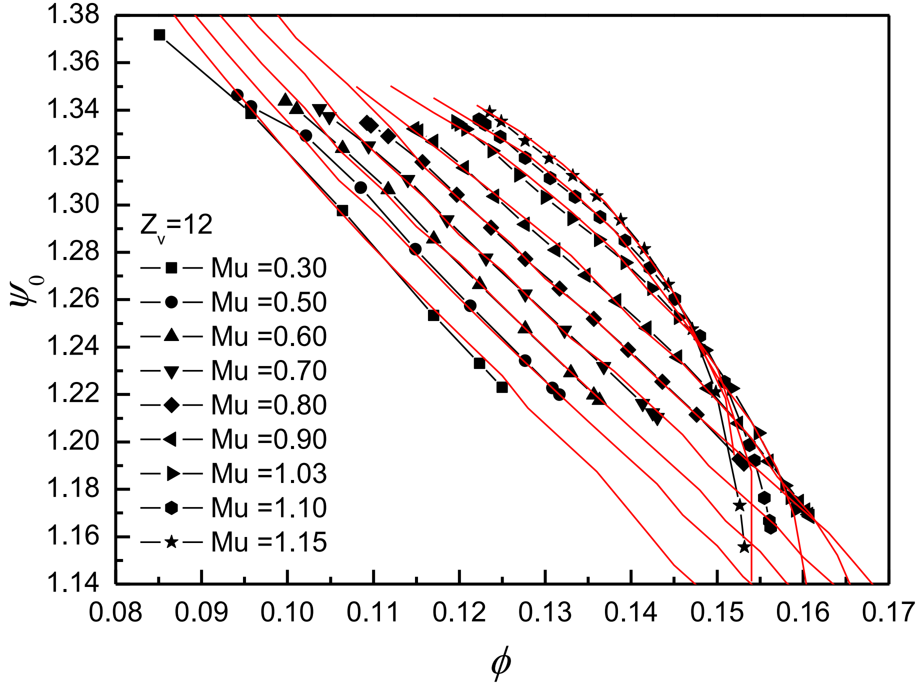
$$= q(\phi_2)$$

$$\frac{\psi_0}{2} = \phi_2 \tan\alpha_2$$

$$\psi_0 = 2\phi_2 \tan\{k(\phi_2)\}$$

$$\psi_0 = p(\phi_2) = p(q^{-1}(\phi)) = f(\phi)$$





conclusion

- **Centrifugal compressor**
  - **- Centrifugal compressor(Z_v=12) data analysis**
  - **- Imp.-diff. matching correlation of the number of vanes**

- **Vaned diffuser**
  - **- Calculation of diverse vaned diffusers(ξ =70°) by CFD**
  - **- Investigation of design parameters**

- **Accumulation of data base : CFD(by SNU), test(by STW)**

- **Development of the in-house program(by MATLAB)**
  - **- 1D aerodynamic design model**
  - **- Performance prediction model**

Thank you for your attention.