EFFECT OF STAGE CHARACTERISTIC PARAMETERS ON GAS TURBINE PERFORMANCE

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ABSTRACT

A theoretical study was carried out to find the effect of the stage characteristic values of the turbine on its performance. This study was made for a general case and some special cases. The effect of mass flow factor, degree of reaction, diameter ratio, peripheral and meridian velocities ratio at inlet and outlet, work done factor, and fixed and moving blade efficiencies on the stage efficiency are represented by several graphs for use in the design of gas turbines.

Keywords: Stage, Chatacteristic parameters, Gas turbine, Performance.

Nomenclature

- C : Absolute velocity.
- D : Impeller diameter.
- r : Degree of reaction $= \Delta i'' / L_u$
- FB : Fixed Blades.
- MB : Moving Blades.
- H : Stage isnetropic enthalpy drop. (total to static)
- U : Peripheral velocity.
- W : Relative velocity.
- α : Angle of absolute velocity.
- β : Angle of relative velocity.
- δ : Boss ratio D_h/D_{et}
- Ψ : Pressure head coefficient $= 2H/U_4^2$
- η_{st} : Stage internal efficiency $= L_u/H$
- φ : Mass flow factor C_{m_4}/U_4
- φ_* : $C_{m_5}/U_4 = \mu\varphi$
- λ : Work done factor $= L_u/(U_4^2/2)$
- υ : Diameter ratio $= D_5/D_4 = U_5/U_4$
- μ : Meridian velocity ratio $= Cm_5/Cm_4$

Superscripts

- ′ : Stator process
- ″ : Rotor process

Subscripts

- 4 : Inlet of impeller
- 5 : Outlet of impeller
- ax : Axial Direction
- m : Meridian direction
- u : Peripheral direction

INTRODUCTION

The turbine designer has the freedom to select a combination of meridian velocities ratio "μ" and the diameter ratio "υ" for a turbine stage. This selection must ensure not only the best efficiency at the design point but also has a small variation in the efficiency over a wide range of other operation conditions, especially for those used in exhaust gas turbochargers, [1,2]. Thus we have what is called optimum value of "μ,υ" combination, and to achieve that we must know the effect of such parameters on the stage efficiency, and that is the aim of the present work. The stage efficiency depends also on the losses occurring in fixed and moving wheels, which depends to a great extent on the turbine geometry such as diameter ratio "υ", blade angles, and also depends on the aerodynamic parameters such as degree of reaction "r", Mach number "M", meridian velocity ratio "μ", work done factor "λ" and mass flow factor "φ". The practical range of "φ" lies between 0.25 to 0.5, [3,4], while the diameter ratio "υ" must be less than 0.8, [5,6], and the value of "μ" ranges from 0.4 to 1.0, [7,8]. The effect of these characteristic parameters on the stage losses has been studied in references [9,10].

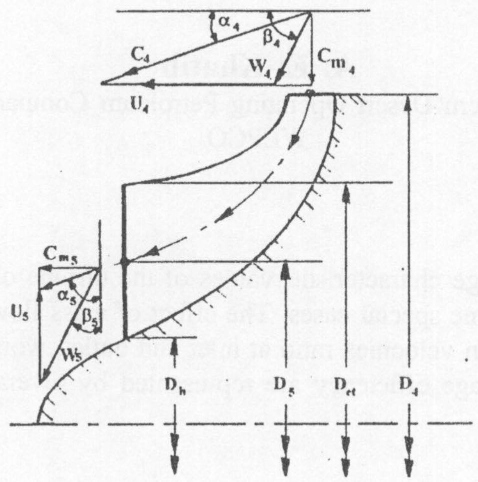

Figure - 1

Blade shape and velocity diagrams for a mixed flow turbine. (General Case)

THEORETICAL ANALYSIS

Considering a turbine stage with fixed and moving wheels and applying the energy and momentum equations, we can get the following equations relating the angles of moving and fixed blades of the turbine with its characteristic parameters for a general case :-

$$(1-\nu^2).\varphi^2.\text{ctg}^2\alpha_4 - \lambda.\varphi\,\text{ctag}_4 + [\frac{\lambda_2}{4} + \upsilon^2.\lambda.(1\text{-r}) - \upsilon^2.\varphi^2.(1\text{-}\mu^2)] = 0.0 \quad (1)$$

[11]

$$(1-\nu^2).\varphi^2.\mu^2\text{ctg}^2\alpha_5 + \lambda.\nu\,\varphi\,\text{ctag}_5 - [\frac{\lambda_2}{4} - \lambda.(1\text{-r}) + \varphi^2.(1\text{-}\mu^2)] = 0.0 \quad (2)$$

$$(1-\nu^2).\varphi^2.\text{ctg}^2\beta_4 + 2(1-\nu^2-\frac{\lambda}{2}).\varphi\,\text{ctag}\,\beta_4 + [\frac{\lambda_2}{4} + \upsilon^2.\lambda.(1\text{-r}) + \upsilon^2.\varphi^2.(\mu^2\text{-}1) + (1\text{-}\upsilon^2) - \lambda] = 0.0 \quad (3)$$

$$(1-\nu^2).\varphi^2.\mu^2\text{ctg}^2\beta_5 + 2(\frac{\lambda}{2} - 1 + \nu^2).\nu.\varphi\mu.\text{ctag}\,\beta_5 - [\frac{\lambda_2}{4} - \lambda.(1\text{-r-}\upsilon^2) + \varphi^2.(1\text{-}\mu^2)] - \upsilon^2(1\text{-}\upsilon^2) = 0.0 \quad (4)$$

(Refer to the nomenclature for the definition of the above characteristic parameters.)

The last relations are valid for all centripetal turbine stages, which can be found in the regulating stage in multi stage turbines or in separate small turbines such as those of an exhaust turbocharger.

To find the different possible solutions of the pervious equations for given values of the parameters "μ, υ", which define the stage dimensions, we can consider the following special cases :-

I- Mixed flow turbine with equal inlet and outlet meridian velocities:-

By substituting "$\mu = 1$" in the previous equations and for "$\upsilon < 1$", we get the corresponding values of blade angles, then:-

$$\text{Ctg}\,\alpha_{4_{(1,2)}} = \frac{\lambda}{2.\varphi.(1-\nu^2)}[1 \pm \nu\sqrt{1-\frac{4}{\lambda}.(1-r)(1-\nu^2)}] \quad (5)$$

$$\text{Ctg}\,\alpha_{5_{(1,2)}} = \frac{-\lambda}{2.\varphi.(1-\nu^2)}[\nu \pm \sqrt{1-\frac{4}{\lambda}.(1-r)(1-\nu^2)}] \quad (6)$$

$$\text{Ctg}\,\beta_{4_{(1,2)}} = \text{Ctg}\,\alpha_{4_{(1,2)}} - \frac{1}{\varphi} \quad (7)$$

$$\text{Ctg}\,\beta_{5_{(1,2)}} = \text{Ctg}\,\alpha_{5_{(1,2)}} + \frac{\nu}{\varphi} \quad (8)$$

The practical range of "α_4" lies between $10° < \alpha_4 < 35°$, then for certain "α_4" and for pre-assumed values of "λ, r and υ" there are two different values of "φ". It is important to choose the smaller value of "φ" to a get low velocity value in the stage and thus insuring lower outlet losses and hence better efficiency. The outlet losses can be more minimized when the absolute outlet velocity from the moving blades "C_5" coincides with the meridian direction, that means "$\alpha_5 = 90°$". Substituting this value in equation (6), we can get the optimum value of "λ" for a known value of "r" to fulfill the condition of minimum outlet losses, which is equal to :

$$\lambda_{opt.} = 4.(1 - r)$$

Thus, it is sufficient now to know "α_4, r, υ" and consider "μ=1" for this case to determine the optimum blade angles "β_4, β_5". As an example for this case, when $\alpha_4 = 20°$, r = 0.5, υ = 0.5, μ = 1 & $\alpha_5 = 90°$ there are two values for φ; $\varphi_1 = 0.364$,

φ_2=0.607. For φ_1=0.364 we find that $\beta_4=\beta_5=90°$, $\beta_5=36°$, and for φ_2=0.607 we find that $\beta_4=42.3°$, $\beta_5=36°$.

In the case of $\lambda=\lambda_{opt.}=4(1-r)$, and on substituting in equation (5) the value "$\mu=1$", then:-

$$\varphi = \frac{2.(1-r)}{(1-\nu^2)}.(1 \pm \nu^2).\tan\alpha_4$$

It can be seen from the last equation that "φ" can only have a positive value in this case when "r<1.0"
It can also be noticed from equations (5, 6) that "α_4, α_5", can have only a single value when :

$$\nu\sqrt{1-\frac{4}{\lambda}.(1-r).(1-\nu^2)} = 0.0$$

as $\upsilon \neq 0.0$ then $\lambda = 4(1-r)(1-\upsilon^2)$ so that:

$$\varphi = 2.(1-r).\tan\alpha_4$$

Substituting these values in equations (7 & 8), we find that:-

$$\text{Ctg}\ \beta_4 = [1 - \frac{1}{2.(1-r)}].\text{ctg}\,\alpha_4 \qquad (9)$$

$$\text{Ctg}\ \beta_5 = [\frac{1}{2.(1-r)} - 1].\nu.\text{ctg}\,\alpha_4 \qquad (10)$$

In this case when r=0.5 we find that $\beta_4=\beta_5=90°$, $W_4 = W_5$. The change in enthalpy in the moving blades in this case will be only due to the change in peripheral velocities at inlet and outlet of the blades.

II- *Mixed flow turbine with different inlet and outlet velocities ($\mu \neq 1$), $\beta_4=\beta_5=90°$ and $\upsilon<1$* .

From Equations (1 & 2) we can get :-

$$\tan\alpha_4 = \sqrt{\frac{(1-2r)(1-\nu^2)}{(1-\mu^2)}} \qquad (11)$$

$$\tan\alpha_5 = \frac{-\mu}{\nu}.\tan\alpha_4 \qquad (12)$$

From equation (11) the degree of reaction "r" can be found as:-

$$r = \frac{1}{2} - \frac{1}{2}.\frac{(1-\mu^2)}{(1-\nu^2)}\tan^2\alpha_4$$

For this special case the work done factor "λ" can be obtained as $\lambda = 2.(1-\upsilon^2)$ and the value of degree of reaction in this case must equal to :-

$$r = \frac{1}{2} - \frac{(1-\mu^2)}{\lambda}\tan^2\alpha_4$$

III- *Mixed flow turbine with different inlet and outlet velocities ($\mu \neq 1$), $\beta_4=\alpha_5=90°$ and with $\upsilon<1$.*

Substituting "$\beta_4=\alpha_5=90°$" in equations (2 & 3) then:-

$$\frac{\lambda^2}{4} + \nu^2.\lambda(1-r) - \nu^2.\varphi^2.(1-\mu^2) + 1 - \nu^2 - \lambda = 0.0 \qquad (13)$$

$$\frac{\lambda^2}{4} - \lambda.(1-r) + \varphi^2.(1-\mu^2) = 0.0 \qquad (14)$$

from these equations (13&14), we can obtain the following equation:-

$$\frac{\lambda^2}{4}.(1+\nu^2) - \lambda + 1 - \nu^2 = 0.0$$

The maximum power which can be obtained in this case is at "λ=2", substituting this value in equations (13 & 14), then:-

$$\varphi = \sqrt{\frac{1-2r}{1-\mu^2}}$$

and therefore:

$$\varphi^* = \mu.\varphi = \sqrt{\frac{1-2r}{\frac{1}{\mu^2}-1}}$$

"φ" can only have a real value for ($r \leq 0.5$) & ($\mu<1$) and for ($r \geq 0.5$) & ($\mu > 1$). Power can be obtained from this turbine only in this case when "φ" has a real value. ("φ" indicates the mass flow rate). It is also clear that "r" is a function of "φ" and "μ" only.

IV- *Axial turbine with different inlet and outlet axial velocity components ($\mu \neq 1$ & $\upsilon=1$).*

When the diameter ratio "υ" tends to unity, the radial stage gradually approaches an axial stage, and on substituting "υ=1" in equations (1, 2, 3 & 4) then :-

$$\text{Ctg}\ \alpha_4 = \frac{1}{\varphi}.(\frac{\lambda}{4} + 1 - r - \frac{\varphi^2}{\lambda}(1-\mu^2)) \qquad (15)$$

$$\text{Ctg}\ \alpha_5 = \frac{1}{\varphi}.(\frac{\lambda}{4} - 1 + r + \frac{\varphi^2}{\lambda}(1-\mu^2)) \qquad (16)$$

$$\text{Ctg}\ \beta_4 = \frac{1}{\varphi}.(\frac{\lambda}{4} - r - \frac{\varphi^2}{\lambda}(1-\mu^2)) \qquad (17)$$

$$\text{Ctg}\ \beta_5 = \frac{1}{\varphi}.(\frac{\lambda}{4} + r + \frac{\varphi^2}{\lambda}(1-\mu^2)) \qquad (18)$$

V- *Axial turbine with equal inlet and outlet axial velocity components ($\mu=1$ & $\upsilon=1$).*

By substituting "$\upsilon=1$" and "$\mu=1$" in equations (1, 2, 3 & 4), we can get the flow and blade angles in terms of "λ, φ and r", as:

$$\text{Ctg}\ \alpha_4 = \frac{1}{\varphi}.(\frac{\lambda}{4} + 1 - r) \qquad (19)$$

$$\text{Ctg}\ \alpha_5 = \frac{1}{\varphi}.(\frac{\lambda}{4} - 1 + r) \qquad (20)$$

$$\text{Ctg}\ \beta_4 = \frac{1}{\varphi}.(\frac{\lambda}{4} - r) \qquad (21)$$

$$\text{Ctg}\ \beta_5 = \frac{1}{\varphi}.(\frac{\lambda}{4} + r) \qquad (22)$$

These relations are represented in Figures (2, 3 & 4). These Figures show the change in "α_5, β_4 & β_5", with the change in "λ". In the practical range of $(2 < \lambda < 4)$ and for all degrees of reaction the rate of change of these angles increase with decreasing "α_4". At the degree of reaction "r=1", "α_5" remains constant for all values of "λ", this constant value of "α_5" decreases with decreasing "α_4", (Figure 2).

The relation between "β_4"and "λ" in Figure (3) shows the same tendency as explained above, and also "β_4" increases with increasing "r" for the same value of "λ", and from $(\lambda > 6)$, the effect of "r" on "β_4" decreases noticeably. The effect of "λ" on "β_5" is represented in Figure (4). This effect is more smaller than that on "β_4" and "α_5". For "r = 0.5", the angle "β_5" has a constant value which increases by increasing "α_4". Also, "β_5" increases with "λ" for "r > 0.5" and decreases with "λ" when (r <0 .5).

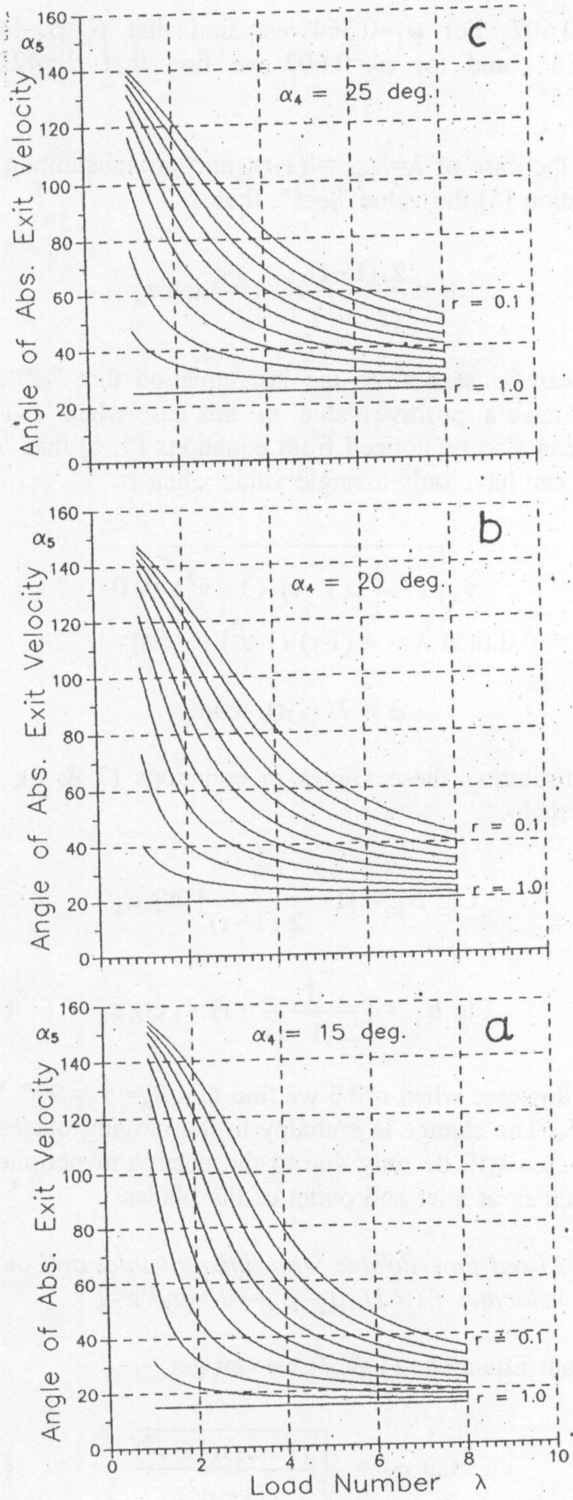

Figure - 2

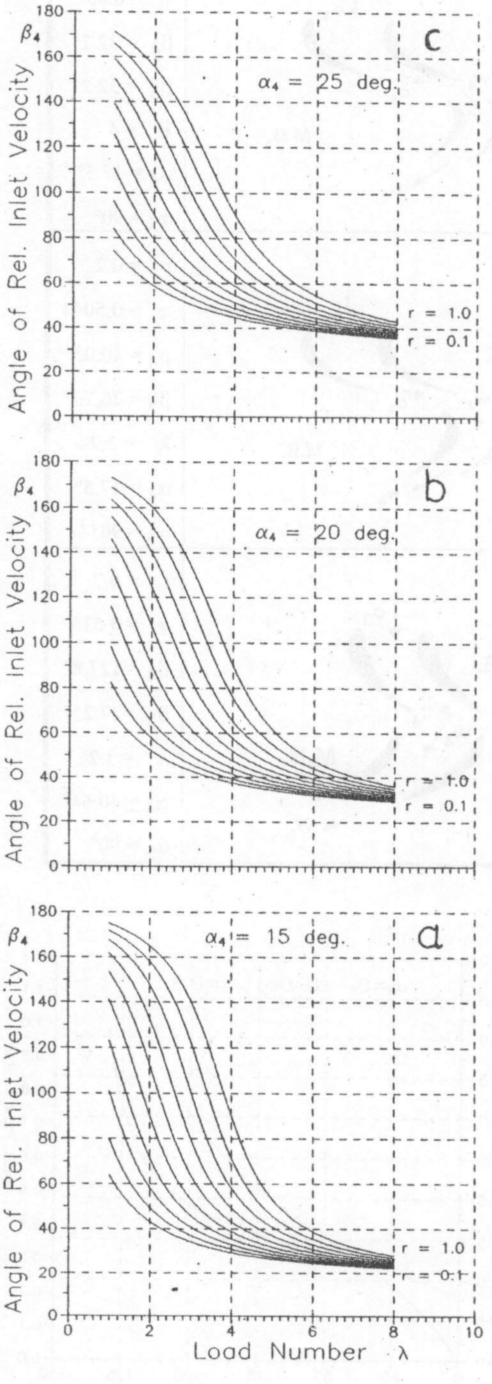

Figure - 3

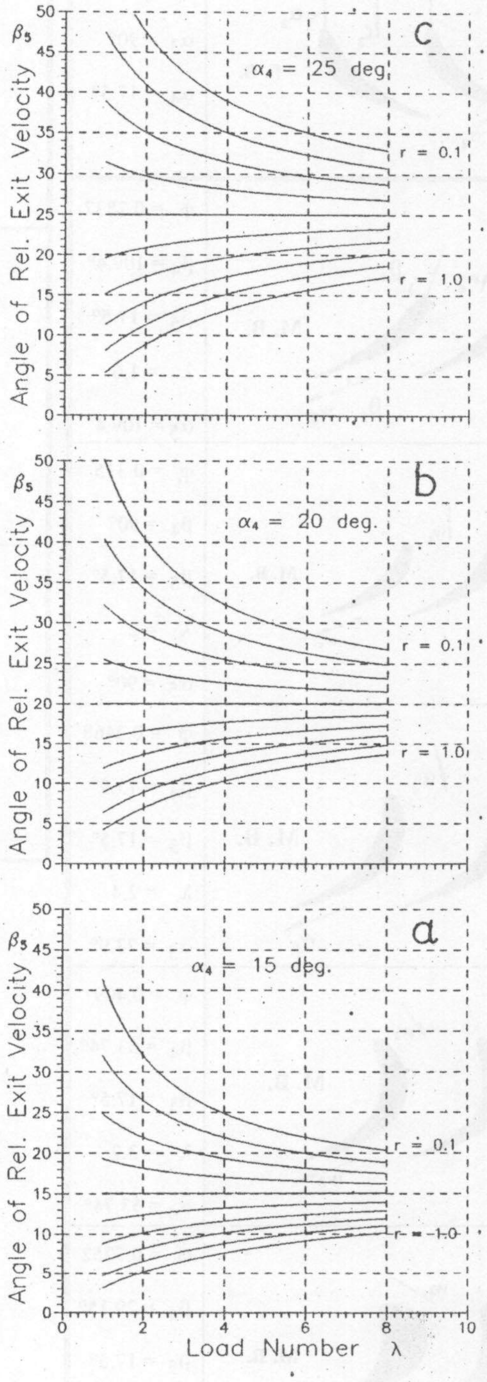

Figure - 4

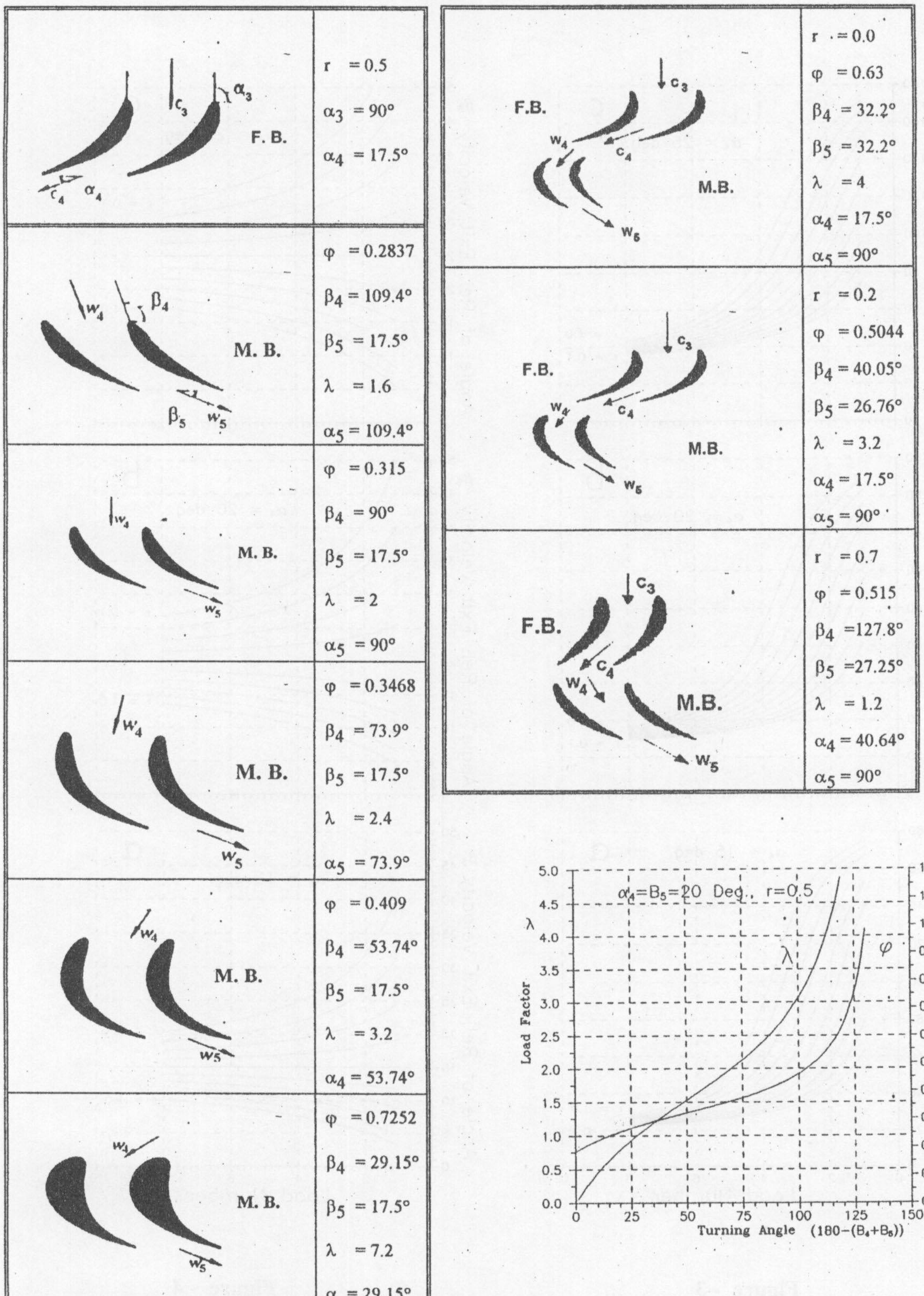
F. B.
r = 0.5
α3 = 90°
α4 = 17.5°
M. B.
φ = 0.2837
β4 = 109.4°
β5 = 17.5°
λ = 1.6
α5 = 109.4°
M. B.
φ = 0.315
β4 = 90°
β5 = 17.5°
λ = 2
α5 = 90°
M. B.
φ = 0.3468
β4 = 73.9°
β5 = 17.5°
λ = 2.4
α5 = 73.9°
M. B.
φ = 0.409
β4 = 53.74°
β5 = 17.5°
λ = 3.2
α4 = 53.74°
M. B.
φ = 0.7252
β4 = 29.15°
β5 = 17.5°
λ = 7.2
α = 29.15°
F.B.
M.B.
r = 0.0
φ = 0.63
β4 = 32.2°
β5 = 32.2°
λ = 4
α4 = 17.5°
α5 = 90°
F.B.
M.B.
r = 0.2
φ = 0.5044
β4 = 40.05°
β5 = 26.76°
λ = 3.2
α4 = 17.5°
α5 = 90°
F.B.
M.B.
r = 0.7
φ = 0.515
β4 = 127.8°
β5 = 27.25°
λ = 1.2
α4 = 40.64°
α5 = 90°
α4=B5=20 Deg., r=0.5
Load Factor
Mass Flow Factor
Turning Angle (180-(B4+B5))

Figure - 5

The effect of the stage characteristic parameters on the blade geometry and configuration is shown in Figure (5) for different cases of "λ, φ & r". It is also clear from this Figure that the rate of change of both "λ", "φ" increase rapidly for turning angles greater than 100°.

EFFECT OF CHARACTERISTIC PARAMETERS ON THE STAGE EFFICIENCY

The following investigations have been carried out for the most common types of turbines, which are :-

i) Mixed flow turbine with $\beta_4=\alpha_5=90°$ $\mu\neq 1$.
ii) Normal axial stage with $\upsilon=1$, $\mu=1$.

I- *Mixed flow turbine with* $\beta_4=\alpha_5=90°$, $\mu\neq 1$.

By applying the turbine basic equations one can get the following relations:-

$$\Psi=\frac{C_4^2}{u_4^2}.(\frac{1}{\eta'}-1)+\frac{1}{\eta''}.(\varphi^{*^2}+\nu^2)+2-\nu^2 \qquad (23)$$

$$\eta_{st}=\frac{2}{\frac{C_4^2}{u_4^2}.(\frac{1}{\eta'}-1)+\frac{1}{\eta''}(\varphi^{*^2}+\nu^2)+2-\nu^2} \qquad (24)$$

$$r=\frac{1}{2}(\varphi^{*^2}-\sqrt{(\frac{C_4^2}{u_4^2}-1)+1}) \qquad (25)$$

With the aid of equations (23, 24, 25) the turbine performance has been expressed in terms of its main characteristic parameters "υ, φ^{*}" and the design values (α_4, η, η'').

From Figures (6, 7, 8) it can be seen that "Ψ" and "r" increase with increasing of "φ^*" while the stage efficiency decreases slightly at first with "φ^*" till ($\varphi^{*''}$=0.3), after that it begins to fall more rapidly. It can also be noticed that "r" is independent of "υ".

By comparing Figures (6-b & 7-b) which have the same values of (η', η''), and with different values of "U_4/C_4", we find that "U_4/C_4" has a negligible effect on "η_{st}", and by comparing Figures (6- b&8-b) which have the same values of (η', U_4/C_4) but with different values of (η''), we find that (η'') has a noticeable effect on "η_{st}".

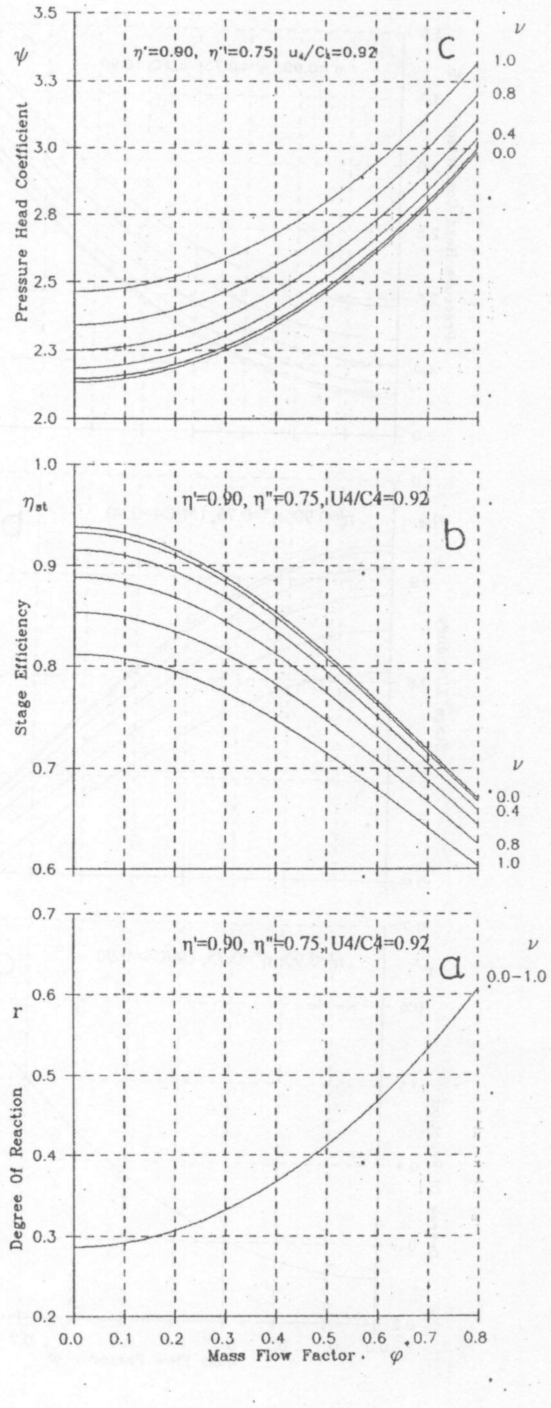

Figure - 6

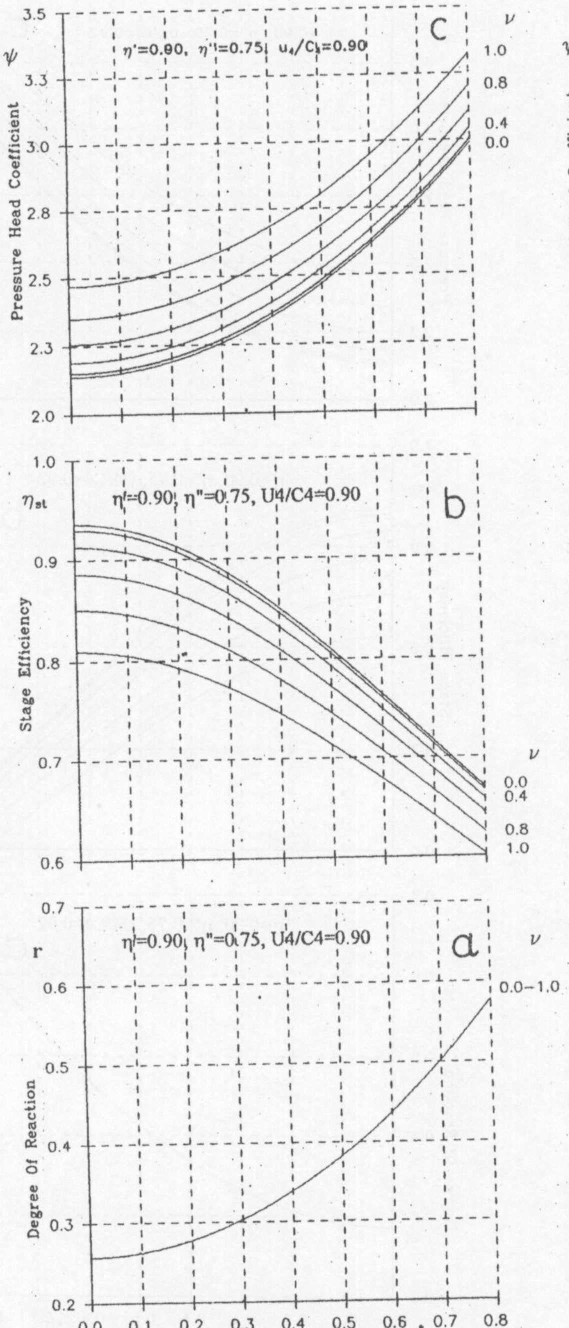

Figure - 7

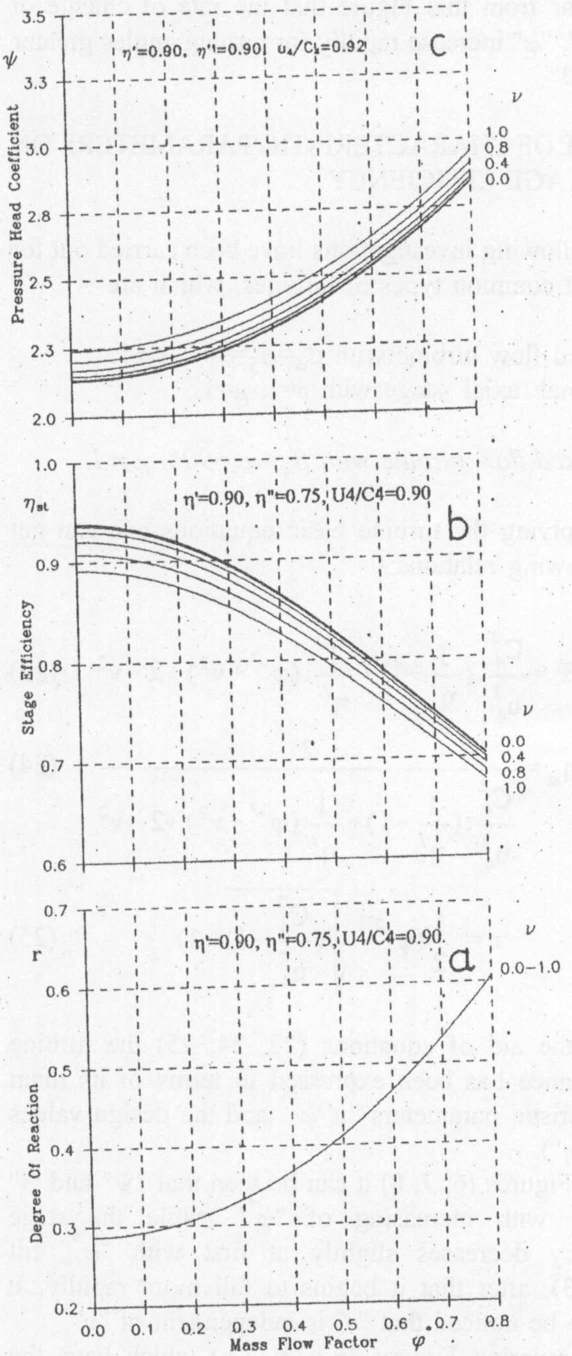

Figure 8

Figure (9) represents the relation between "υ" and "φ^*" for certain value of "η_{st}" and for different values of (η", U_4/C_4). By comparing Figures (a & c) and (a & b) of the same Figure, we find that the effect of (η'') on this relation is more greater than that of "U_4/C_4" for the same value of "η_{st}".

Figures (10 & 11) show the relation between "U_4/C_4" and "Ψ, η_{st} & r". It is clear from these Figures that for constant value of "υ & φ^*", "U_4/C_4" has a negligible effect on "Ψ & η_{st}" within the practical range of "U_4/C_4" ($0.98 > U_4/C_4 > 0.82$).

The Figures show also that the degree of reaction increases rapidly with increasing of "U_4/C_4". The intersection of these curves with the horizontal coordination represents the impulse turbine case (r=0), the corresponding value of "U_4/C_4" increases with decreasing of "φ^*". It is also clear from this Figure that "r" is independent of "υ".

Figure (12) represents the relation between "υ" and "η_{st}" for certain values of "φ''^*" and for different values of (η") and "U_4/C_4". By comparison it is clear that (η'') has a greater effect on the stage efficiency than that of "U_4/C_4".

Figure (13) represents the relation between "r" and "η_{st}" for certain values of "U_4/C_4". It can be seen from this Figure that the stage efficiency decreases by increasing the degree of reaction, and by comparing the results of (a & b) and (a & c) of the same Figure, it can be noticed that the effect of (η'') on this relation is greater than that of "υ".

The effect of "φ^*" on the diameter ratio "υ" for different values of (η'') is represented in Figure (14 - a & b) for two different values of stage efficiency "η_{st}". It is clear from these Figures that "υ" tends to (∞) with the increase of (η''), while "φ^*" tends to a certain limit, this limit decreases by increasing of "η_{st}".

Figure (15) shows the relation between "U_4/C_4" and "μ" for certain constant values of "φ^*". We find here that the rate of change of "μ" increases by increasing "φ^*" and "μ" tends to "∞" as "U_4/C_4" tends to unity.

The effect of "φ^*" on "μ" for constant values of "U_4/C_4" is represented also in Figure (16). This Figure shows that the relation between "μ" and "φ^*" is linear, and the rate of change of "μ" with respect to "φ^*" increases with increasing "U_4/C_4". This relation is important for turbine design to get the correct value of "μ" corresponding to the pre-assumed value of "φ^*, U4/C4". The relation between "φ^*, μ & U4/C4" can be deduced as :-

$$\mu = \varphi^* / \left(\sqrt{\frac{C_4^2}{U_4^2}} - 1\right) \qquad (26)$$

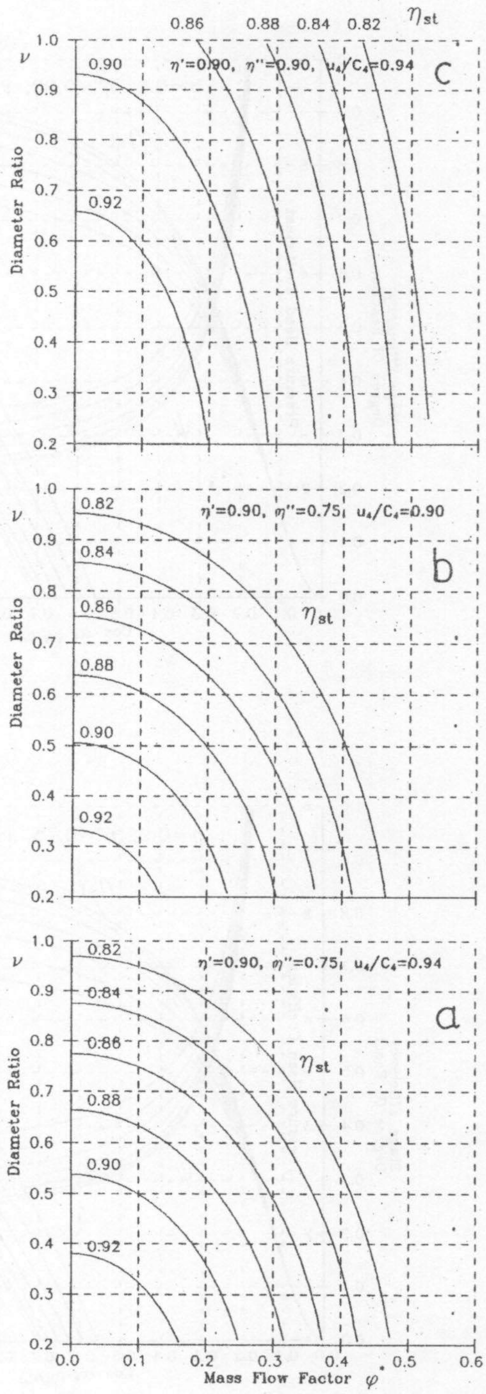

Figure - 9

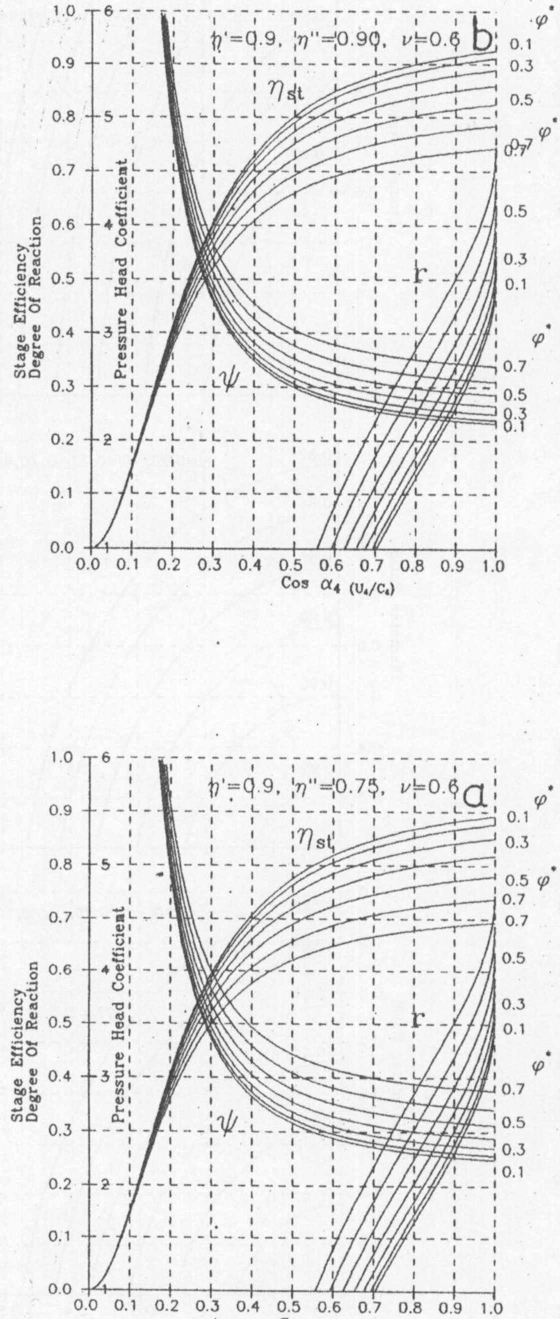

Figure - 10

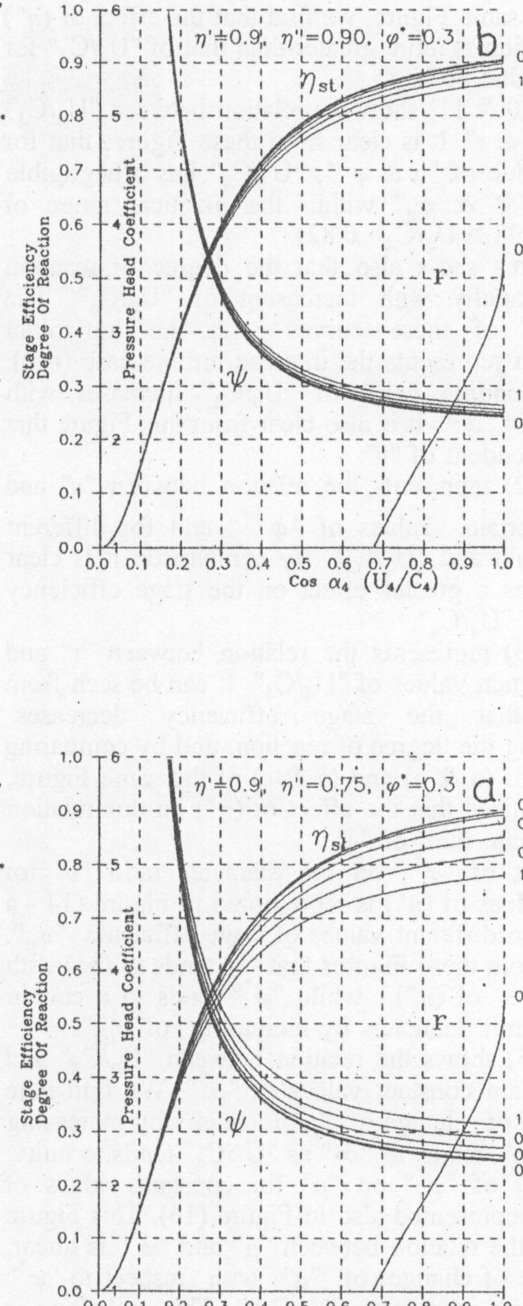

Figure - 11

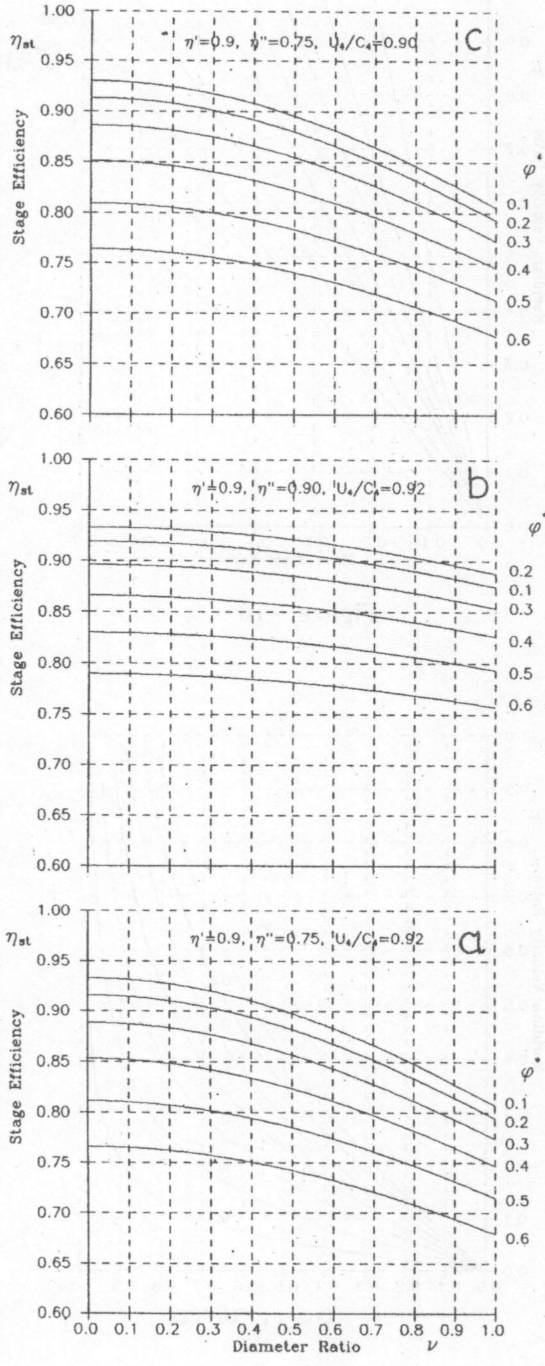

Figure - 12

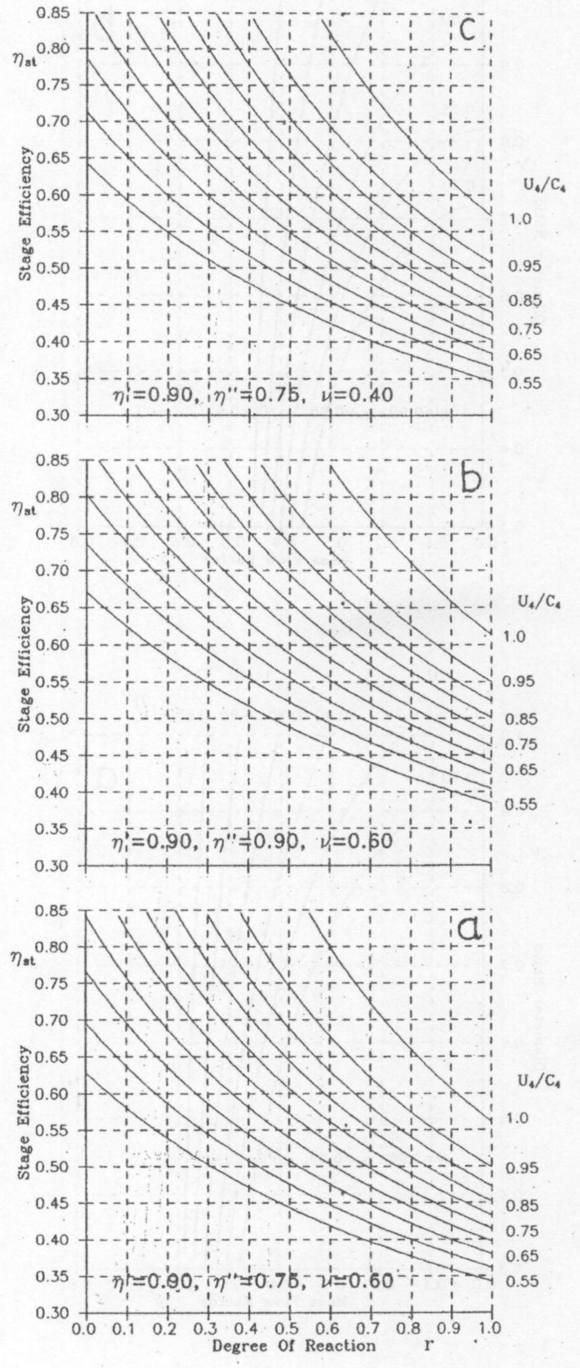

Figure - 13

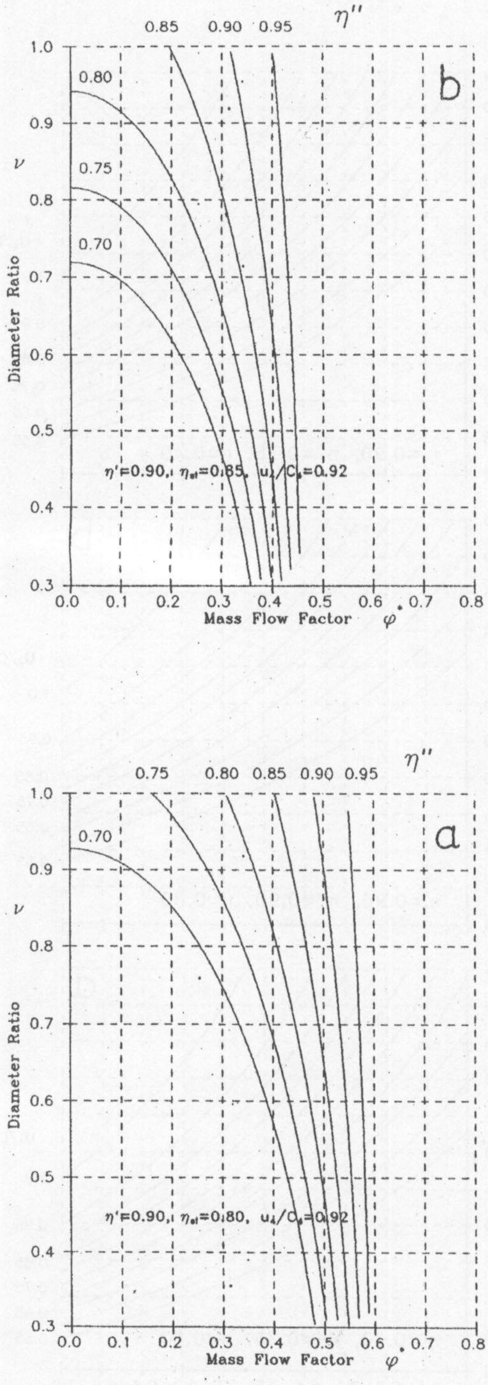

Figure - 14

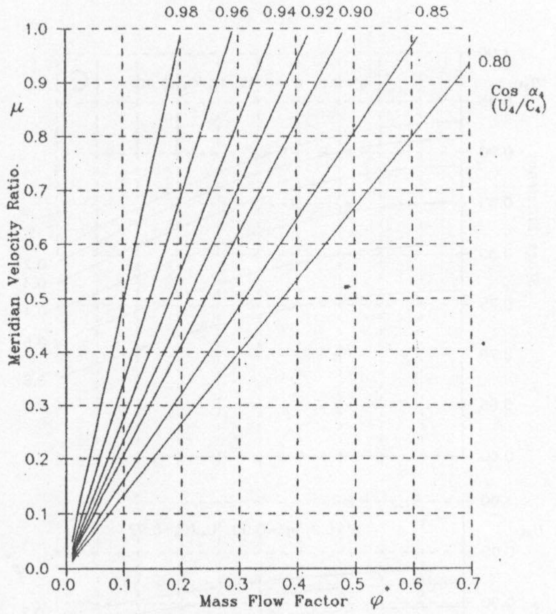

Figure - 16

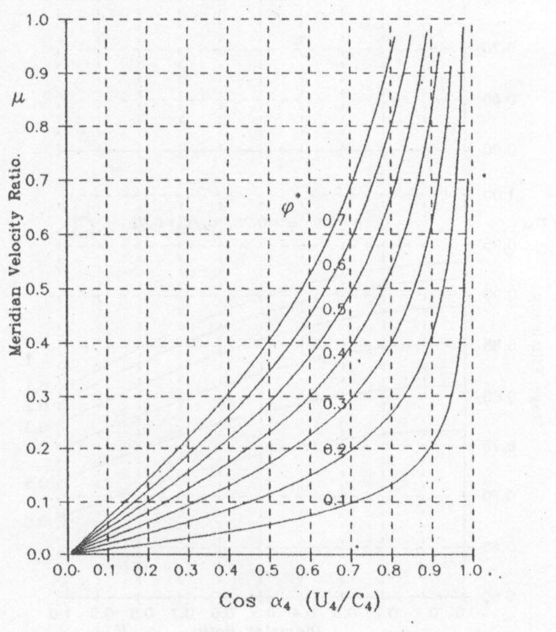

Figure - 15

Calculation of stage mean efficiency of mixed flow turbine

The stage efficiency obtained from previous equation (24) represents the efficiency of the turbine for the mean stream line of the flow. By calculating the stage efficiency for different stream lines over the inlet and cutlet area of the turbine, that means at different values of "υ" and consequently "η_{st}", and by integrating this value over the outlet cross-section, we can get the stage mean efficiency as :-

$$\bar{\eta}_{st} = \frac{8}{D_{et}^2 - D_h^2} \cdot \int_{R=\frac{D_h}{2}}^{R=\frac{D_{et}}{2}} \eta_{st} R . dR \qquad (27)$$

The last equation (27) can be solved graphically by plotting the relation between " η_{st}. R $8/(D_{et}^2 - D_h^2)$" and "R", and calculating the area under curve between "$R = D_h/2$" and "$R = D_{et}/2$" as shown in Figure (17), from which the mean stage efficiency can be obtained for different values of boss ratio "δ". Therefore, with the aid of Figure (12), we can get "η_{st}" at different values of "υ" between "$R = D_h/2$" and "$R = D_{et}/2$".

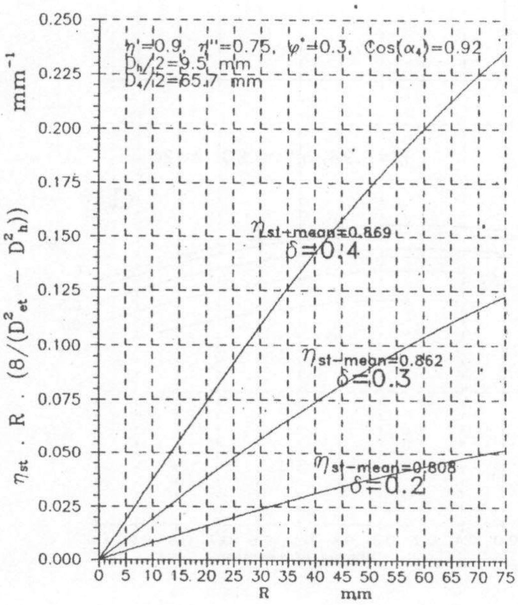

Figure - 17

ii) Normal axial stage with $\upsilon=1$, $\mu=1$.

The relation between the stage efficiency and the characteristic parameters of the turbine can be deduced from the basic equations of turbines and from the definitions of characteristic parameters, so that :

$$\eta_{st} = \frac{\lambda}{\frac{(1-\eta')}{\eta'}.((\frac{\lambda}{4}+1-r)^2+\varphi^2)+\frac{(1-\eta'')}{\eta''}.((\frac{\lambda}{4}+r)^2+\varphi^2)+\lambda} \qquad (28)$$

By partially differentiating equation (28) with respect to "r", we find that the maximum stage efficiency "η_{st}" occurs at "$r_{opt.}$":

$$r_{opt} = \frac{\frac{\lambda}{4}(\frac{1}{\eta'} - \frac{1}{\eta''}) + (\frac{1}{\eta'} - 1)}{(\frac{1}{\eta'} + \frac{1}{\eta''} - 2)} \qquad (29)$$

Figure (18) represents the relation between "η_{st}", "λ" (with "φ" as an independent variable and for certain values of η', η''" and r). This relation shows that "η_{st}" increases with "λ" for all values of "φ", but at a certain value of "λ" this relation becomes more flat and the change of "η_{st}" due to variation of "λ" becomes negligible. The value of "λ" at which "η_{st}" becomes nearly constant increases by increasing the degree of reaction.

Figure (19) gives the relation between "η_{st}" and "r", with "φ" as an independent variable and for some given values of (η', η''" and λ).

Figure (20) represents the relation between "η_{st}" and "φ", with "r" as an independent variable, and for different values of (η', η'' and λ). This Figure shows that the stage efficiency decreases by increasing "φ" and the curves become more flat as "λ" increases.

Figure (21) represents the relation between "η_{st}" and "r" with η'' as an independent variable, for certain values of (η', φ & λ). This relation shows that the stage efficiency has a maximum value at $r = r_{opt.}$ (equation 29). This Figure shows also that η'' has a greater effect on "$r_{opt.}$" than that of "λ".

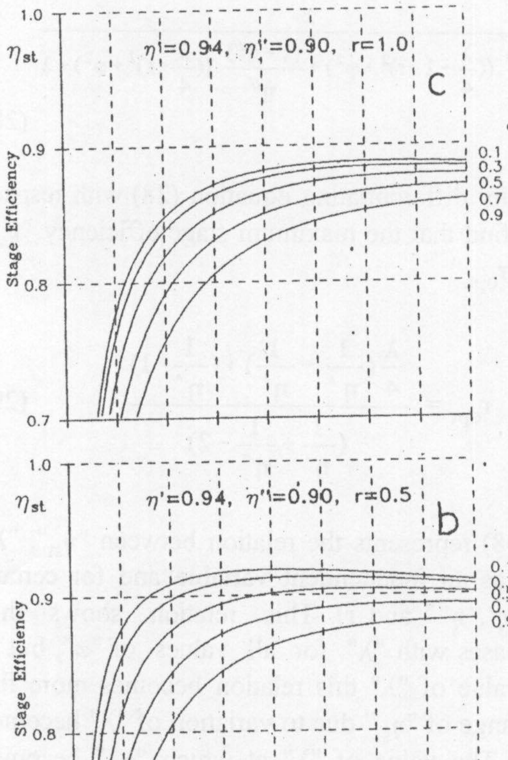

Figure - 18

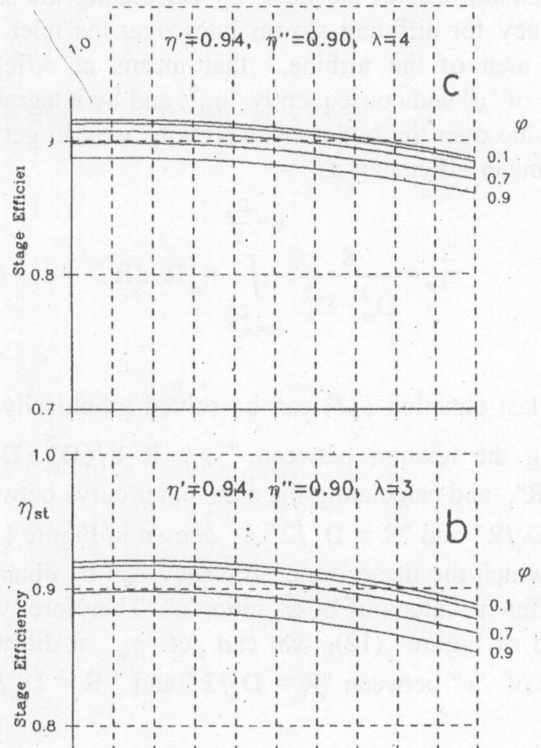

Figure - 19

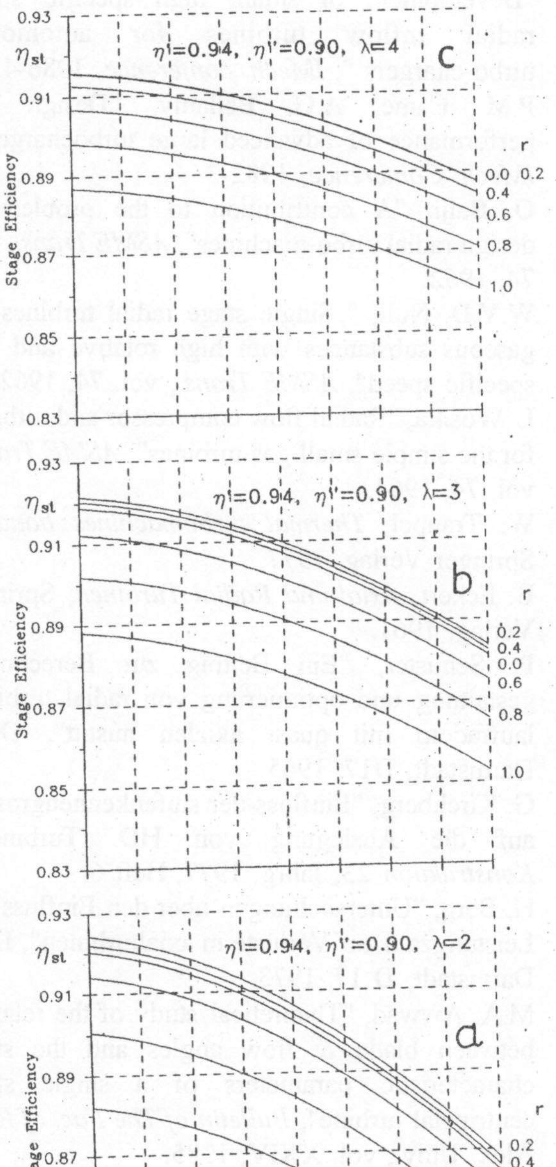

Figure - 20

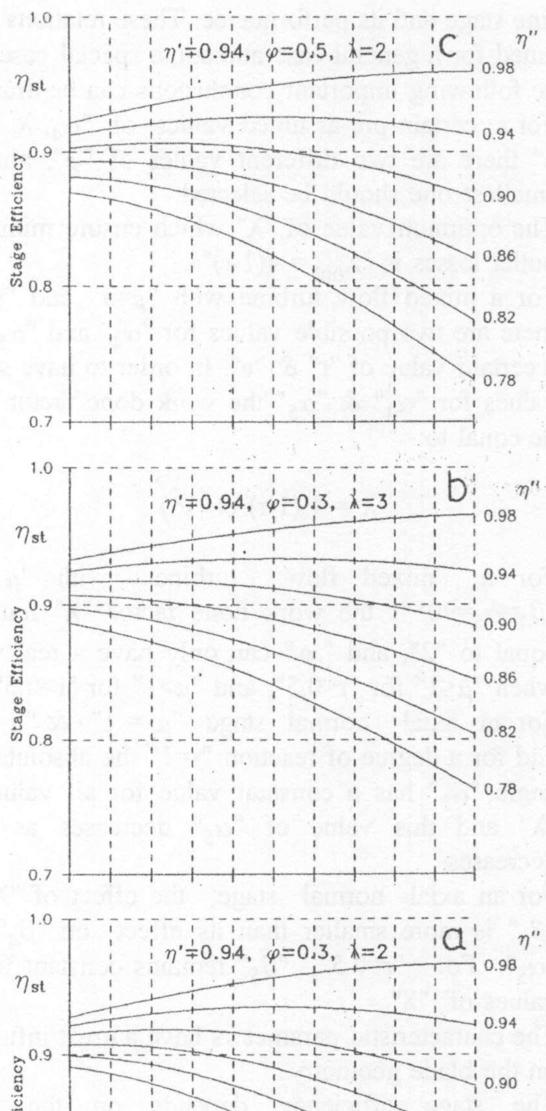

Figure - 21

CONCLUSIONS

Theoretical investigation have been carried out to find the relation between the characteristic parameters of a turbine stage and its performance. These relations were obtained for a general case and some special cases.

The following important conclusions can be drawn :-

1- For a certain pre-assumed values of "α_4, λ, r and υ" there are two different values of "φ", and the smallest one should be selected.

2- The optimum value of "λ" which ensure minimum outlet losses is "$\lambda_{opt.} = 4(1\text{-}r)$"

3- For a mixed flow turbine with "μ=1" and "υ<1", there are two possible values for "α_4" and "α_5" for a certain value of "r" & "υ". In order to have single values for "α_4" & "α_5" the work done factor must be equal to:-

$$\lambda = 4\ (1\text{-}r)\ (1\text{-}\ \upsilon^2)$$

4- For a mixed flow turbine with "$\mu \neq 1$", "$\beta_4 = \alpha_5 = 90°$", the work done factor "λ" must be equal to "2", and "φ" can only have a real value when "μ<1" for "r<0.5", and "μ>1" for "r>0.5".

5- For an axial normal stage "μ = 1" & "υ = 1", and for a degree of reaction "r=1" the absolute exit angle "α_5" has a constant value for all values of "λ" and this value of "α_5" decreases as "α_4" decreases.

6- For an axial normal stage, the effect of "λ" on "β_5" is more smaller than its effect on "β_4" and "α_5". For "r=0.5", "β_5" remains constant for all values of "λ".

7- The characteristic parameters have a great influence on the blade geometry.

8- The stage efficiency depends on the stage parameters, and this stage efficiency is influenced by the moving wheel efficiency η".

9- For a mixed flow turbine with "$\mu \neq 1$", "$\beta_4 = \alpha_5 = 90°$", the effect of "U_4/C_4" on the stage efficiency "η_{st}" is negligible within the practical range of the speed ratio "U_4/C_4" ($0.98 > U_4/C_4 > 0.82$).

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