LECTURE 2

IMPULSE AND REACTION STAGE DESIGN

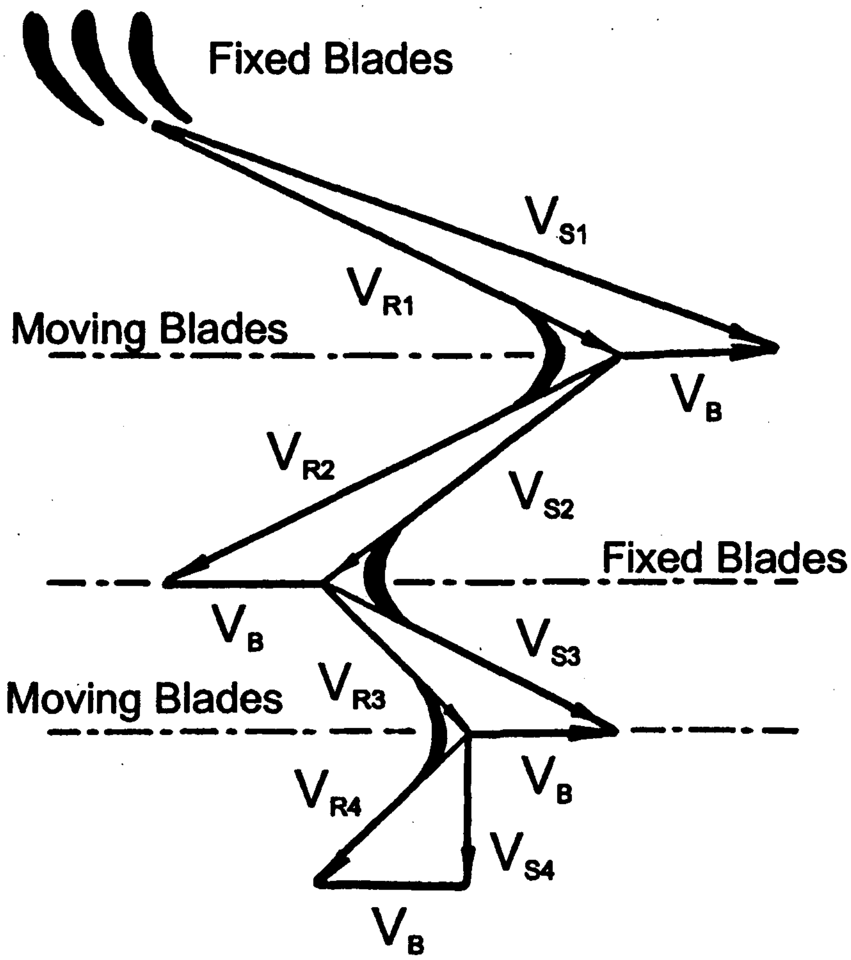
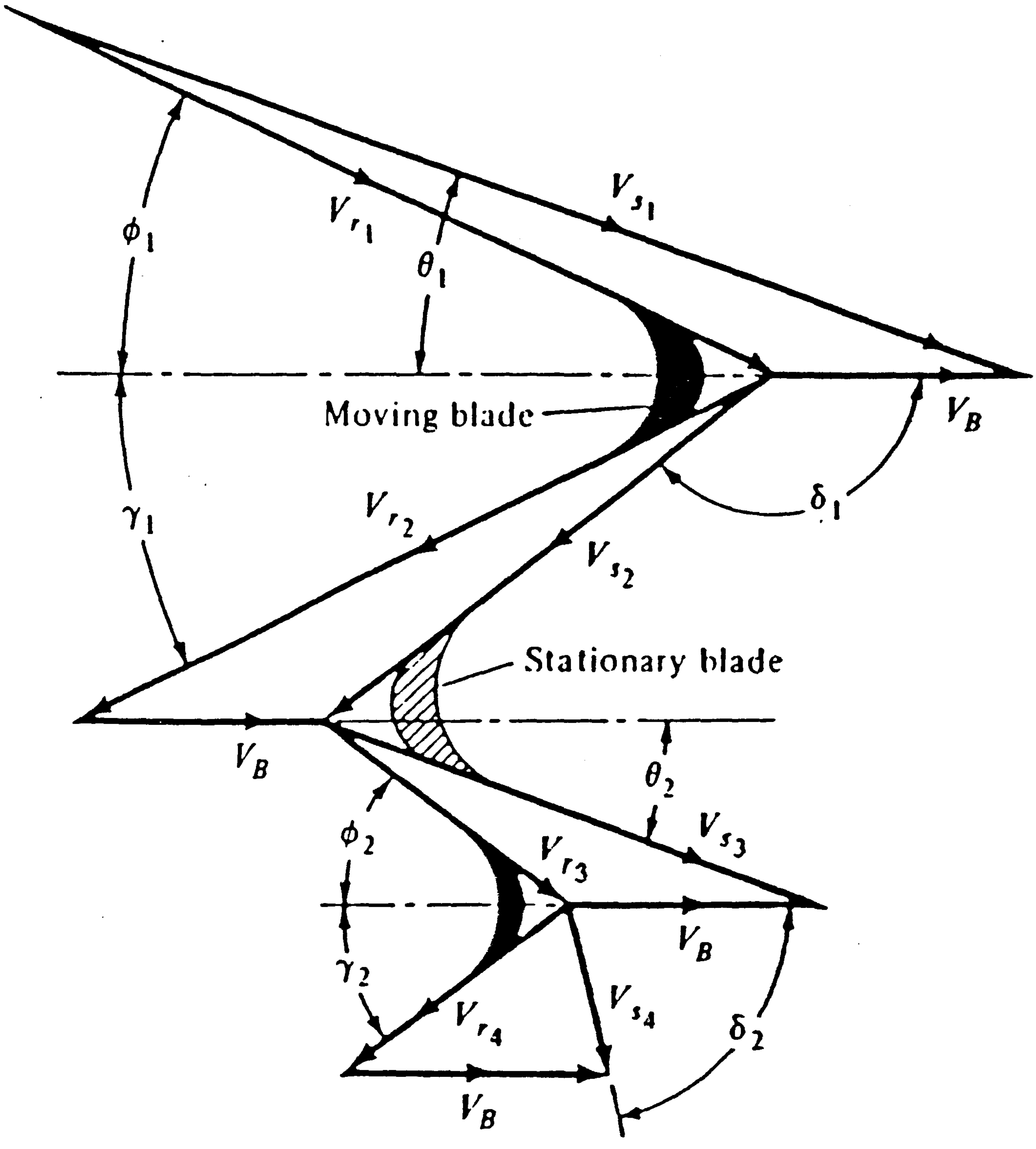


Figure 12 Two stage velocity compounded impulse turbine



V_{s_1}
V_{r_1}
ϕ_1
θ_1
Moving blade
V_B
δ_1
γ_1
V_{r_2}
V_{s_2}
Stationary blade
V_B
θ_2
V_{s_3}
ϕ_2
V_{r_3}
V_B
γ_2
V_{s_4}
V_{r_4}
δ_2
V_B

FIGURE 5.9

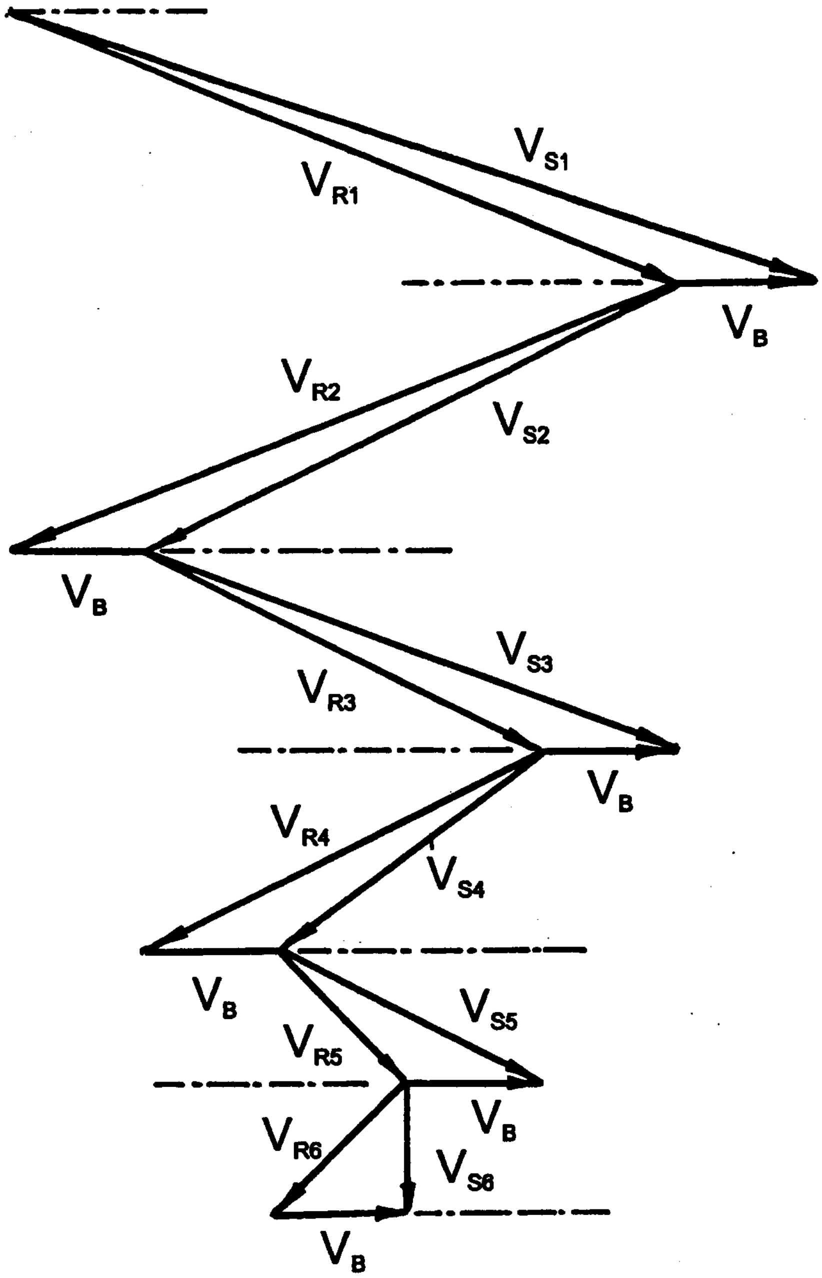


Figure 13 Three stage velocity compounded impulse turbine

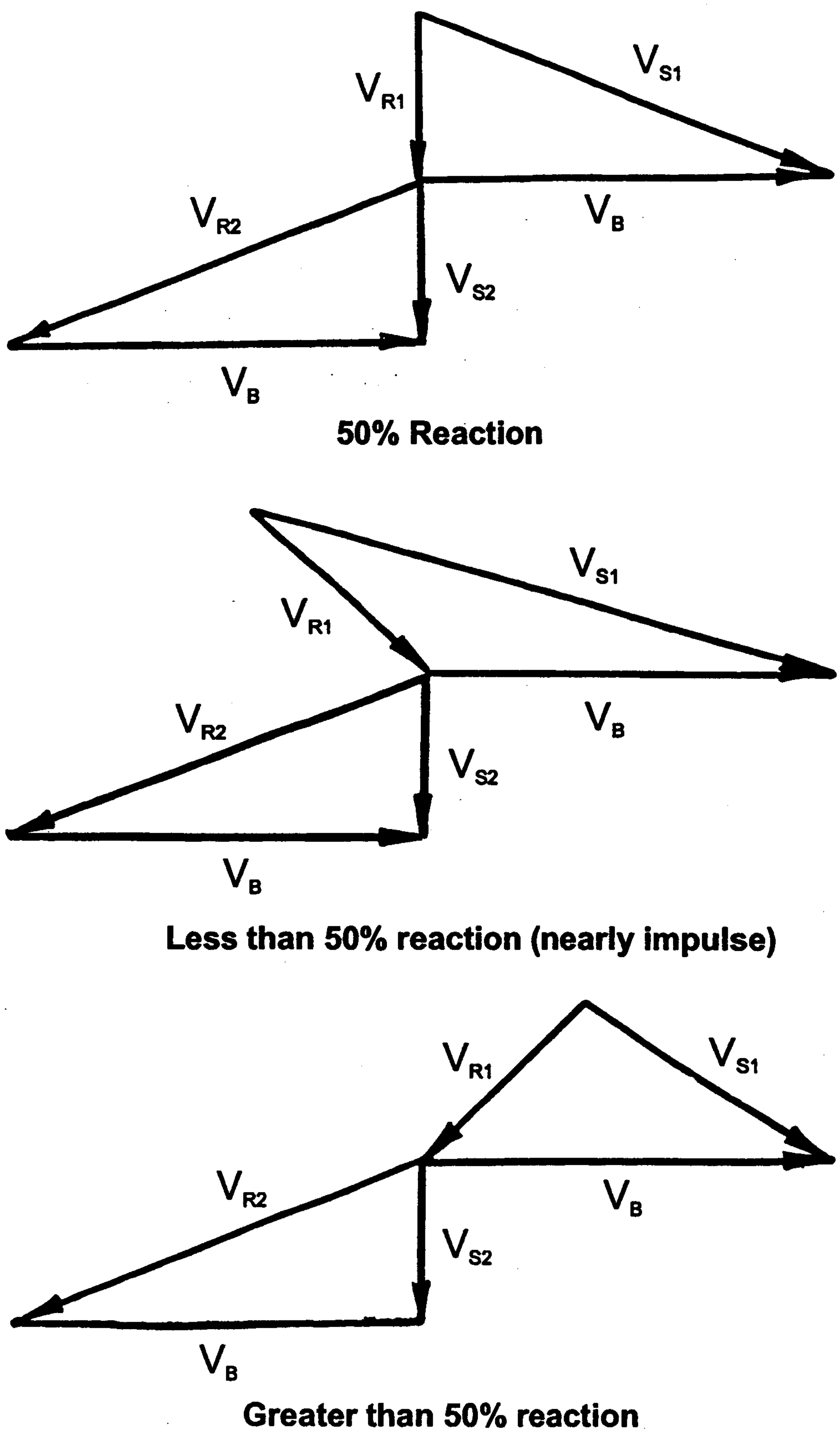
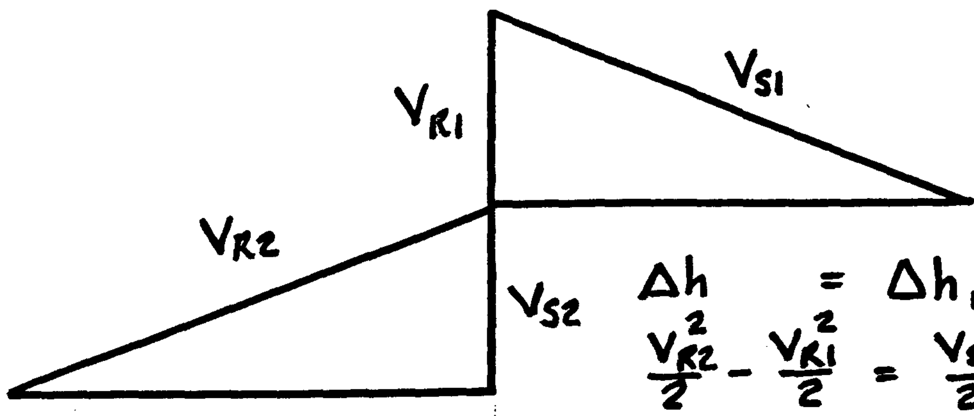


Figure 14 Degree of reaction in turbine blades

REACTION BLADING

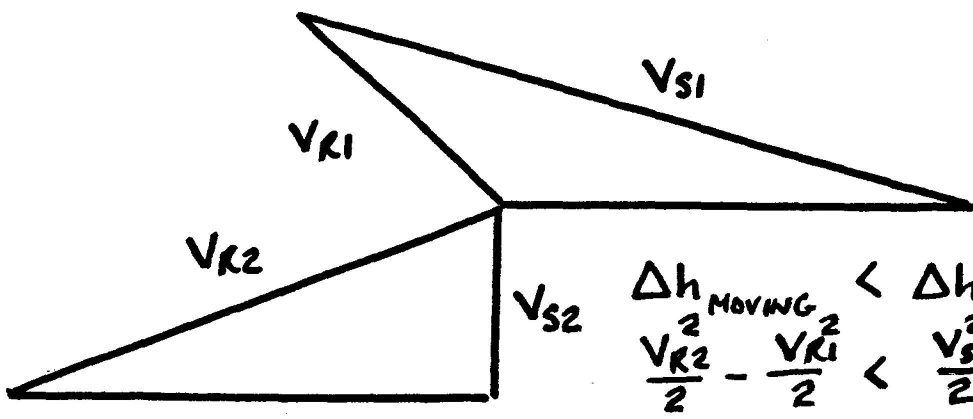
50% REACTION



$$\Delta h = \Delta h_{FIXED}$$

$$\frac{V_{R2}^2}{2} - \frac{V_{R1}^2}{2} = \frac{V_{S1}^2}{2} - \frac{V_{S2}^2}{2}$$

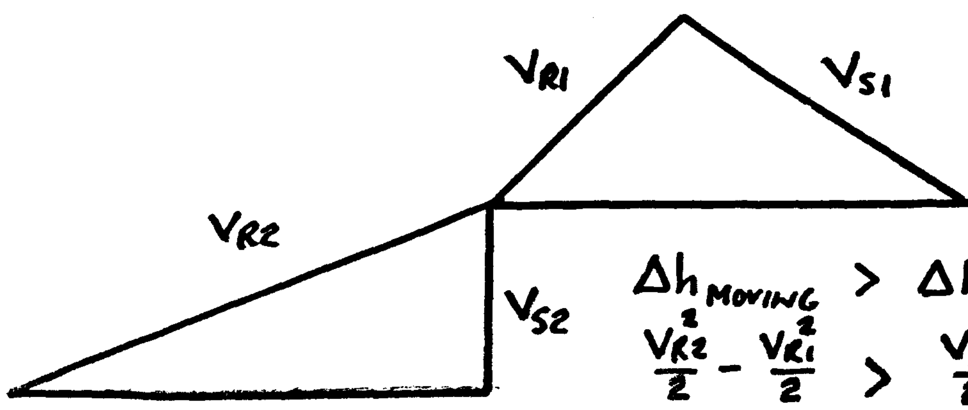
LESS THAN 50% REACTION (NEARLY IMPULSE)



$$\Delta h_{MOVING} < \Delta h_{FIXED}$$

$$\frac{V_{R2}^2}{2} - \frac{V_{R1}^2}{2} < \frac{V_{S1}^2}{2} - \frac{V_{S2}^2}{2}$$

GREATER THAN 50% REACTION



$$\Delta h_{MOVING} > \Delta h_{FIXED}$$

$$\frac{V_{R2}^2}{2} - \frac{V_{R1}^2}{2} > \frac{V_{S1}^2}{2} - \frac{V_{S2}^2}{2}$$

FIGURE 5.10A

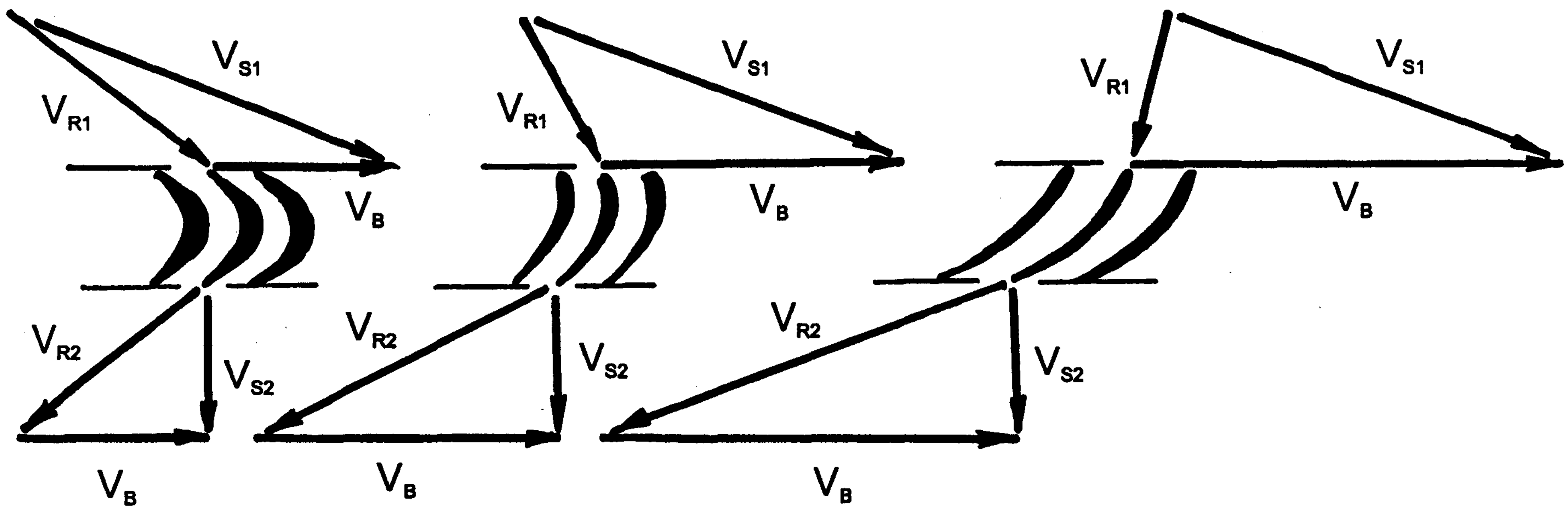
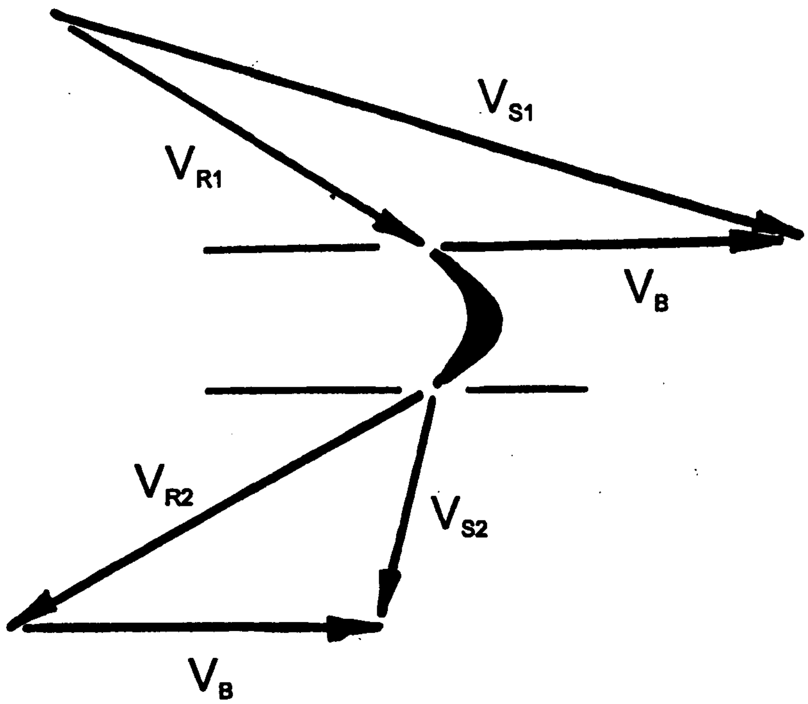
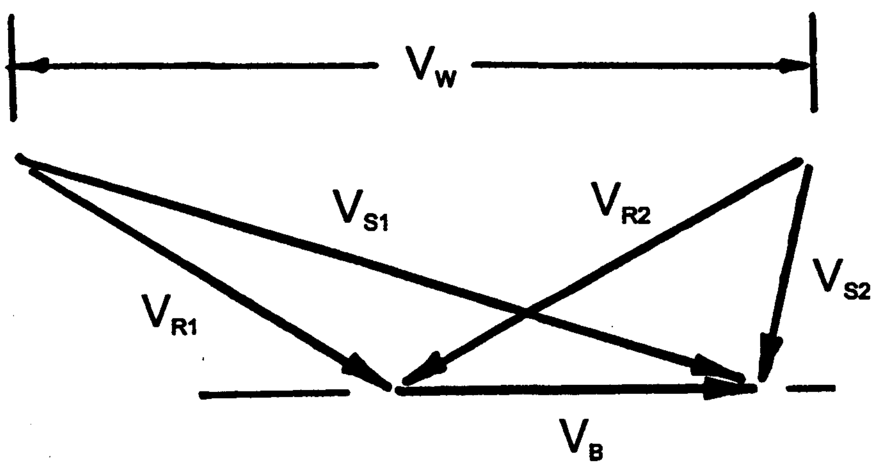


Figure 15 Change in reaction along a twisted turbine blade

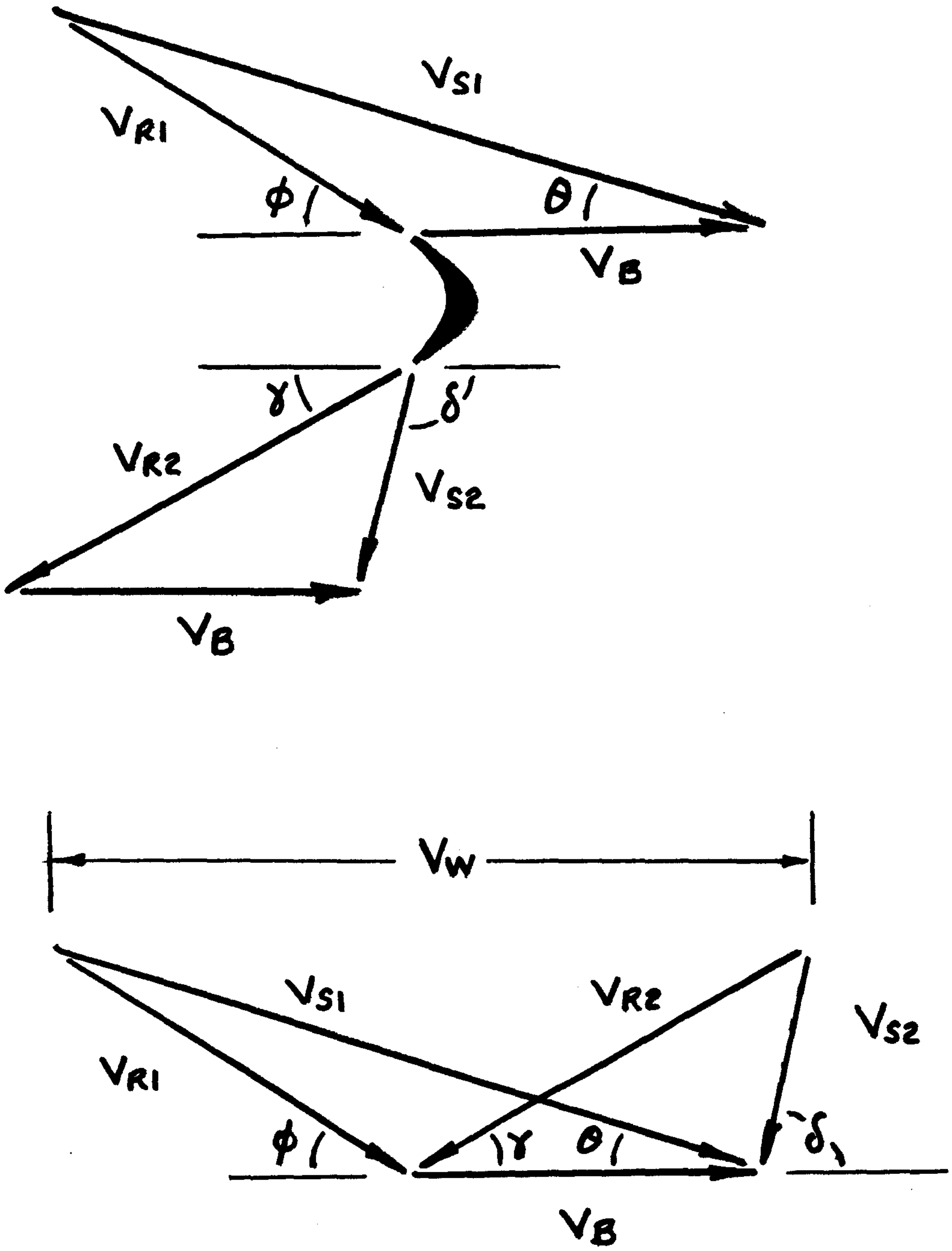


Conventional diagram



Combined diagram

Figure 16 Velocity diagram showing whirl velocity



V_{S1}
V_{R1}
ϕ
θ
V_B
γ
δ
V_{R2}
V_{S2}
V_B
V_W
V_{S1}
V_{R2}
V_{S2}
V_{R1}
ϕ
γ
θ
δ_1
V_B

FIGURE 5.11

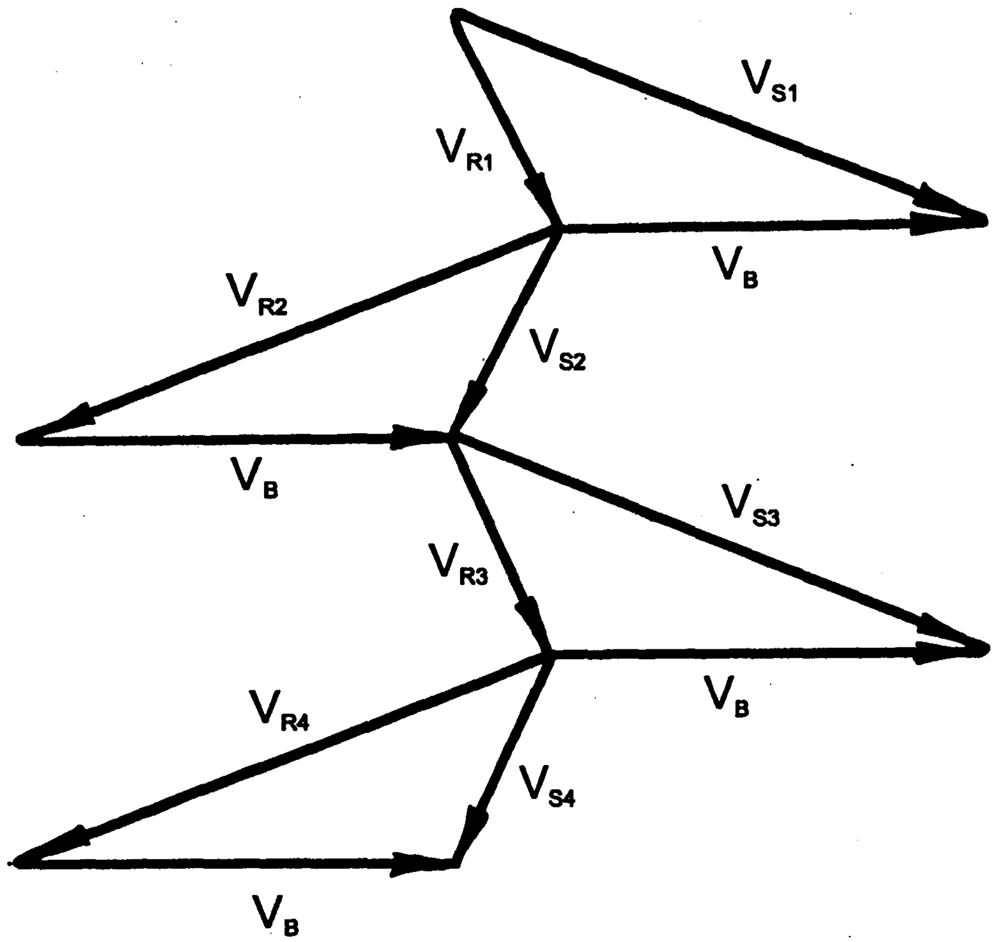


Figure 17 Reaction turbine velocity diagram with increased whirl velocity

Impulse Blading

$$V_{B\ opt} = \frac{1}{2} V_{S1} \cos \theta$$

$$\Delta h_{fixed} = \frac{1}{2} (V_{S1}^2 - V_{SO}^2)$$

$$= \frac{1}{2} (V_{S3}^2 - V_{S2}^2) \text{ for next stage}$$

$$\Delta h_{moving} = \frac{1}{2} (V_{R2}^2 - V_{R1}^2)$$

$$= 0$$

$$P_{impulse} = \frac{1}{2} M (V_{S3}^2 - V_{S2}^2)$$

Reaction Blading

$$V_{B\ opt} = V_{S1} \cos \theta$$

$$\Delta h_{fixed} = \frac{1}{2} (V_{S1}^2 - V_{SO}^2)$$

$$= \frac{1}{2} (V_{S3}^2 - V_{S2}^2) \text{ for next stage}$$

$$\Delta h_{moving} = \frac{1}{2} (V_{R2}^2 - V_{R1}^2)$$

$$= \frac{1}{2} (V_{S3}^2 - V_{S2}^2) \text{ for 50\% reaction}$$

$$P_{reaction} = \frac{1}{2} M [(V_{S3}^2 - V_{S2}^2) + (V_{R2}^2 - V_{R1}^2)]$$

$$= \frac{1}{2} M [(V_{S3}^2 - V_{S2}^2) + (V_{S3}^2 - V_{S2})^2]$$

$$= M (V_{S3}^2 - V_{S2}^2)$$

NUMBER OF STAGES

Impulse Blading

$$\Delta h_{total} = n\,\Delta h_{fixed}$$

$$= n\frac{1}{2}(V_{S1}^2 - V_{S2}^2)$$

$$= n\frac{1}{2}((4V_B^2 / \cos^2\theta) - V_{S2}^2)$$

$$\approx n2V_B^2$$

$$n \approx \Delta h_{total} / 2V_B^2$$

Reaction Blading

$$\Delta h_{total} = n(\Delta h_{fixed} + \Delta h_{moving})$$

$$= n(V_{S1}^2 - V_{S2}^2)$$

$$= n((V_B^2/\cos^2\theta) - V_{S2}^2)$$

$$\approx n\,V_B^2$$

$$n = \Delta h_{total} / V_B^2$$

STAGE EFFICIENCY

GENERAL ENERGY EQUATION WITH FRICTION

$$z_0 g + \frac{V_0^2}{2} + h_0 + w_{IN} + q_{IN} = z_1 g + \frac{V_1^2}{2} + h_1 + w_{OUT} + q_{OUT} + e_{FRICTION}$$

FOR TURBINE CONDITIONS

$$\frac{V_0^2}{2} + h_0 = \frac{V_1^2}{2} + h_1 + e_{FRICTION}$$

$$h_0 - h_1 - e_{FRICTION} = \frac{V_1^2}{2} - \frac{V_0^2}{2}$$

$$\Delta h_{ISENTROPIC} - e_{FRICTION} = \frac{V_1^2}{2} - \frac{V_0^2}{2}$$

THE SAME VELOCITIES WOULD BE ACHIEVED

BY THE ACTUAL ENTHALPY DROP

$$\Delta h_{ACTUAL} = \frac{V_1^2}{2} - \frac{V_0^2}{2}$$

COMBINING THESE EQUATIONS

$$\Delta h_{ACTUAL} = \Delta h_{ISENTROPIC} - e_{FRICTION}$$

$$\Delta h_{ISENTROPIC} = \Delta h_{ACTUAL} + e_{FRICTION}$$

STAGE EFFICIENCY IS GIVEN BY

$$\eta = \Delta h_{ACTUAL} / \Delta h_{ISENTROPIC}$$

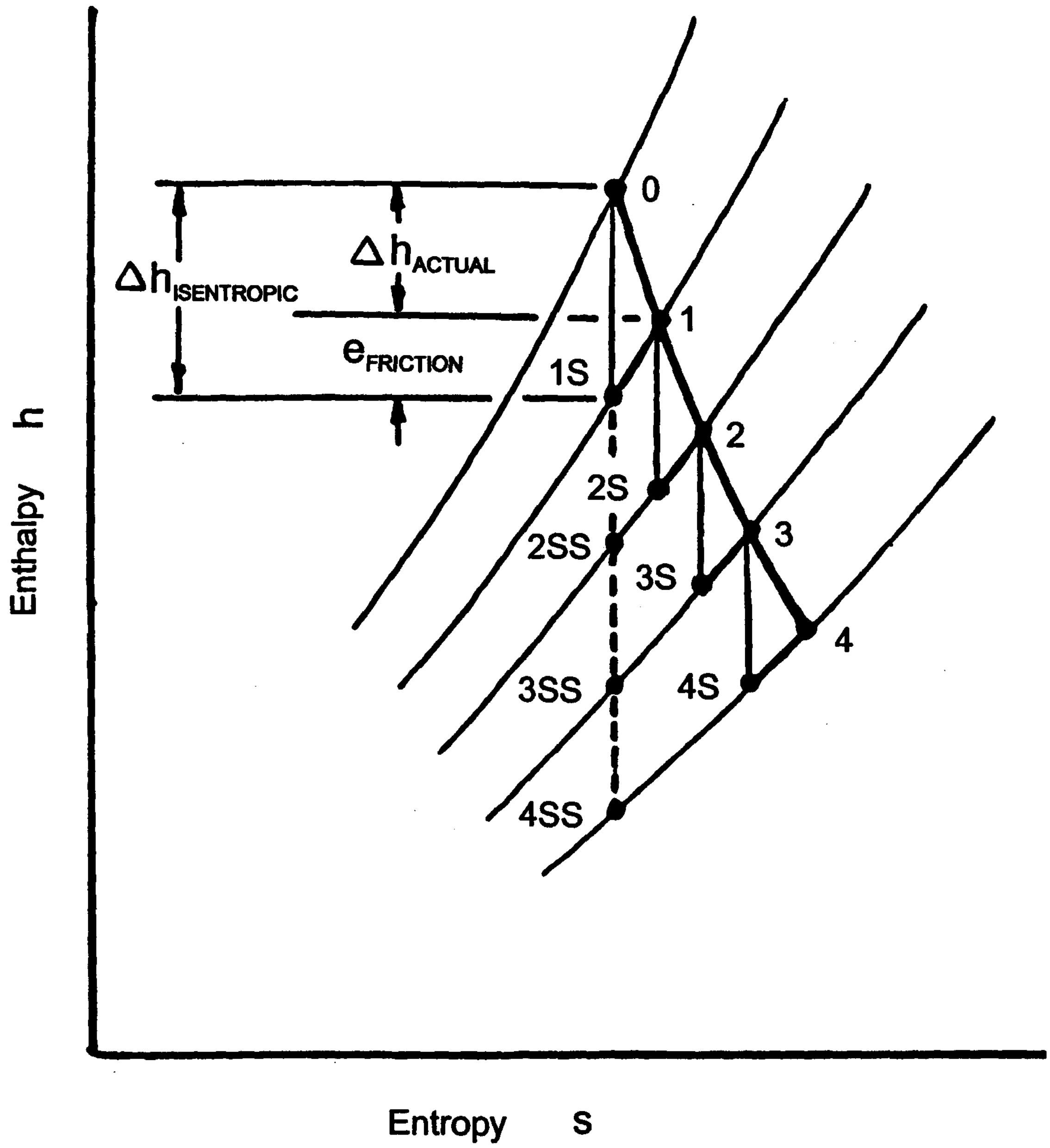


Figure 18 Turbine expansion line showing stage efficiency