Impulse Turbine Velocity Triangles and Blade Efficiency

Velocity triangles of a single-stage impulse (De Laval) turbine: blade angles, whirl, work per kg, power, axial thrust and diagram efficiency, with the maximum efficiency.

Method: Velocity triangles of an impulse stage (textbook)

Input parameters

Unit system: SI

Parameter	Value	Unit
Steam velocity leaving the nozzle	600.00	m/s
Nozzle angle to the plane of the wheel	20.000	°
Mean blade speed	250.00	m/s
Blade outlet angle	Symmetric blades (outlet = inlet angle)	
Blade outlet angle (when given)	30.000	°
Blade velocity coefficient V_r2 / V_r1	0.90000	
Steam flow	3,600.0	kg/h

Calculated results

Parameter	Value	Unit
Whirl velocity at inlet $V_1 \cos \alpha$	563.82	m/s
Flow velocity at inlet $V_1 \sin \alpha$	205.21	m/s
Relative velocity at inlet	374.96	m/s
Blade inlet angle	33.182	°
Relative velocity at outlet	337.46	m/s
Change in whirl velocity	596.25	m/s
Work per kg of steam U ΔV_w	149.06	kJ/kg
Power developed	149.06	kW
Axial thrust	20.521	N
Diagram (blading) efficiency 2 U ΔV_w / V_1^2	82.812	%
Blade speed ratio U / V_1	0.41667	
Best blade speed ratio cos α / 2	0.46985	
Maximum diagram efficiency at the best ratio	83.887	%

Formula and method

$$V_{w1} = V_1 \cos\alpha, \quad V_{f1} = V_1 \sin\alpha, \quad \tan\beta_1 = \frac{V_{f1}}{V_{w1} - U}$$

$$V_{r2} = k\,V_{r1}, \quad \Delta V_w = V_{w1} + V_{r2}\cos\beta_2 - U$$

$$w = U\,\Delta V_w, \quad \eta_d = \frac{2U\Delta V_w}{V_1^2}, \quad \eta_{max} = \frac{\cos^2\alpha}{2}\,(1 + k\,c), \quad c = \frac{\cos\beta_2}{\cos\beta_1}\ (= 1 \text{ for symmetric blades})$$

$$P = \dot{m}\,w, \quad F_a = \dot{m}\,(V_{f1} - V_{f2}), \quad V_{f2} = V_{r2}\sin\beta_2$$

Variables

V_1	Steam velocity leaving the nozzle	m/s
α	Nozzle angle to the plane of the wheel	rad
U	Mean blade speed	m/s
blades	Blade outlet angle	-
β_2	Blade outlet angle (when given)	rad
k	Blade velocity coefficient V_r2 / V_r1	-
$\dot{m}$	Steam flow	kg/s
V_{w1}	Whirl velocity at inlet $V_1 \cos \alpha$	m/s
V_{f1}	Flow velocity at inlet $V_1 \sin \alpha$	m/s
V_{r1}	Relative velocity at inlet	m/s
β_1	Blade inlet angle	rad
V_{r2}	Relative velocity at outlet	m/s
ΔV_w	Change in whirl velocity	m/s
W	Work per kg of steam U ΔV_w	J/kg
P	Power developed	W
F_a	Axial thrust	N
η_d	Diagram (blading) efficiency $2 U \Delta V_w / V_1^2$	-
ρ	Blade speed ratio U / V_1	-
ρ_{opt}	Best blade speed ratio $\cos \alpha / 2$	-
η_{max}	Maximum diagram efficiency at the best ratio	-

Method and standards

Euler's turbine equation applied to the inlet and outlet velocity triangles of a single impulse stage.

Assumptions and limits

- Single stage, single row; no leakage or windage.
- Angles measured from the plane of the wheel.
- A blade speed above the whirl velocity gives negative work, with a note. If the outlet angle makes the maximum-efficiency ratio unphysical (above 100 %), η_max is not shown.
- With a given outlet angle, a relative inlet angle within 1° of 90° (blade speed equal to the whirl component) is rejected: $\cos \beta_1$ is then near zero and the maximum efficiency is not defined.

References

• Velocity triangles of an impulse stage (textbook)

Report details

Report reference	FCC-HJ4R-TQC2 (the same inputs always give the same reference)
Generated	17 November 2026, 19:50 UTC
Calculator	Impulse Turbine Velocity Triangles and Blade Efficiency
Method last reviewed	12 November 2026
Software release	FireCAD Calc, release of 17 November 2026
Release checks	3 reference cases of this calculator, computed independently, are checked on every release

Results are for engineering estimation. Verify critical designs against the referenced standards and your own data.

This calculator online

https://calc.firecad.com/boilers-power-plant/turbines-cycles/impulse-turbine-blade-efficiency

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Reopens the calculator with the inputs of this report.