

# TURBOMACHINERY AERODYNAMICS CONSULTING

Industrial Compressor & Turbine  
Design, Performance Analysis,  
Application and Troubleshooting

## TURBINE AERODYNAMICS

Axial-Flow and Radial-Inflow Turbine  
Design and Analysis

By Ronald H. Aungier

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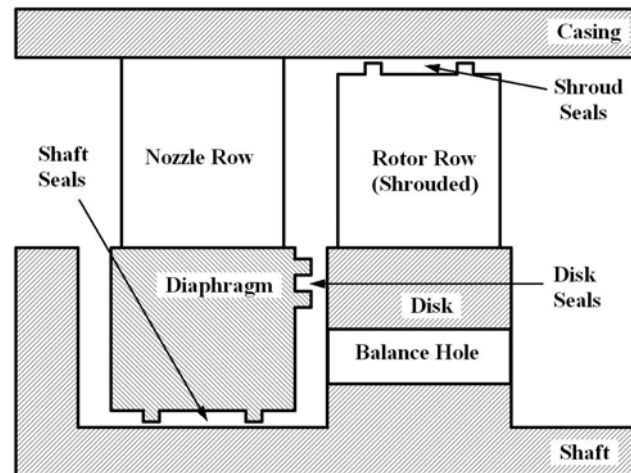
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**Instructions:** This input data form supplies the geometry required for an axial-flow turbine aerodynamic performance analysis using program *AxTurb*. For multistage turbines, some sections will need to be supplied more than once.

**Reference:** Aungier, R. H., *Turbine Aerodynamics: Axial-Flow and Radial-Inflow Turbine Design and Analysis* (ASME Press, New York, 2006).

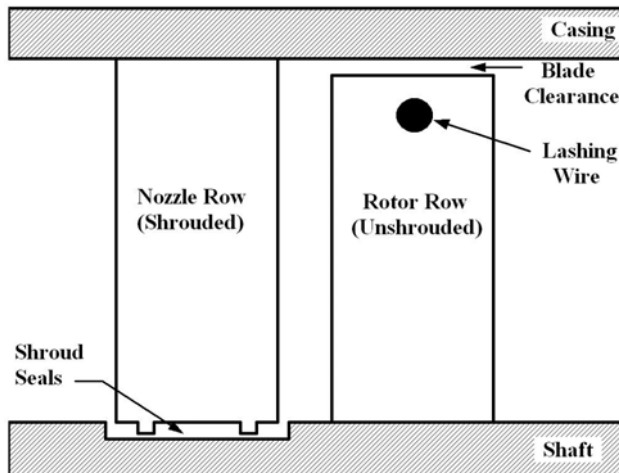
Program *AxTurb* considers two basic turbine stage configurations: diaphragm-disk or drum-rotor styles as shown on figures 1 and 2. A stage generally consists of a nozzle followed by a rotor, but special provision is available to consider a four-row Curtis stage. In that case, the third row is designated as a reversing row rather than as a nozzle. The analysis is conducted the same way in either case, but the performance of the four-row stage is summarized separately for purpose of evaluation.

The major difference in the input data required for the two types of construction is the blade row seal geometry required. The diaphragm disk style also requires definition of the disk axial gaps as well as the disk and shaft radii. It may include balance holes and disk seals as well. Reversing rows may be modeled as a diaphragm-disk style or with axial gap seals as shown on figure 3. Blades may be shrouded or unshrouded, although with diaphragm-disk construction, nozzles and reversing rows are really “shrouded” by definition.

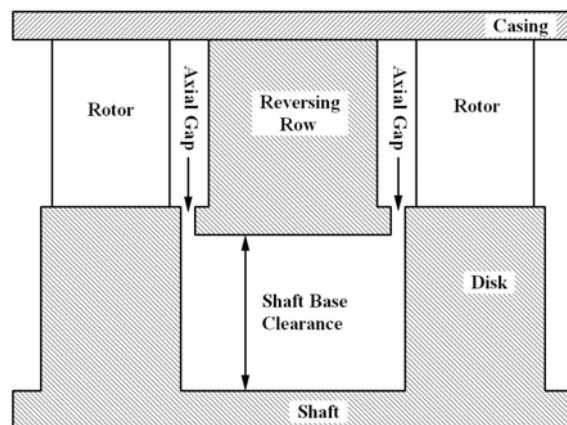


**Figure 1: Diaphragm-Disk Construction**

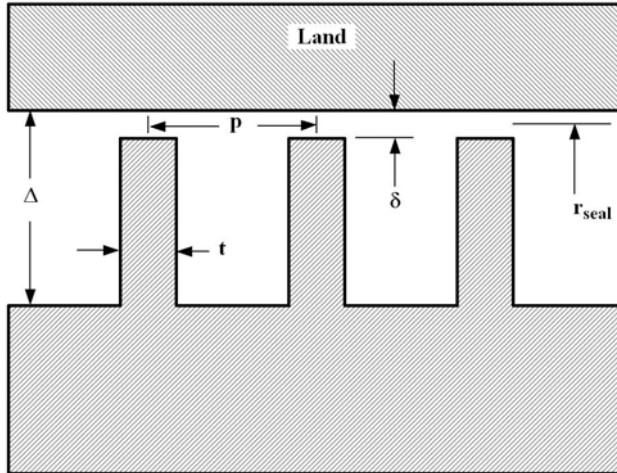
Program *AxTurb* can analyze single-stage and multistage turbines. Provision is made for an optional shaft seal downstream of the turbine. When it is to be included, the temperature and pressure downstream of the seal and the seal geometry must be supplied. In the case of the diaphragm-disk construction, consideration of the shaft seal of the first stage diaphragm (or inlet guide vane) is also optional and requires specification of the upstream pressure and temperature for seal leakage to be considered.



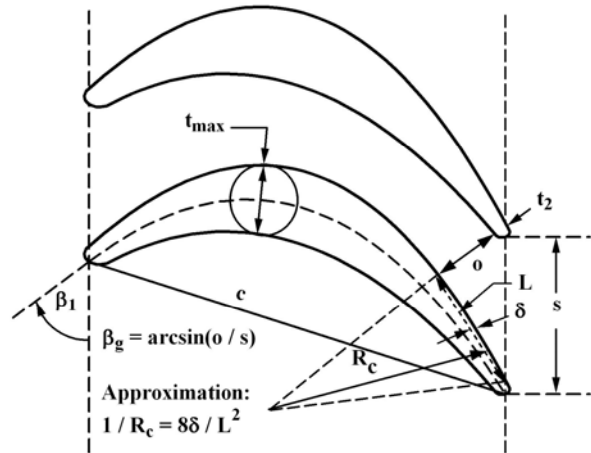
**Figure 2: Drum-Rotor Construction**



**Figure 3: Reversing Row with Axial Gap Seals**



**Figure 4: labyrinth Seal Geometry**



**Figure 5: Blade Section Geometry Nomenclature**

The basic components recognized by the program are vaneless passages, nozzle rows, rotor rows, reversing rows and guide vanes. The last component simply allows for stationary vanes that are not included in the logical definition of a stage. Exhaust diffusers are not analyzed specifically, but an exhaust loss coefficient can be included to account for a diffuser's influence on performance. An exhaust loss does not affect the analysis directly. Rather, it identifies the fraction of the discharge velocity pressure ( $P_{total} - P_{static}$ ) that is lost in the diffuser to arrive at a turbine discharge pressure and the efficiency associated with it. A turbine performance analysis is conducted for either an assigned mass flow rate (applicable only if no blade rows are choked) or an assigned discharge static pressure. In the latter case, the discharge static pressure is associated with the last computing station in the turbine, i.e., it is not influenced by an assigned exhaust loss. In other words, an exhaust loss coefficient will result in an estimate of the influence of an exhaust diffuser for the conditions analyzed, but it is not used to define the operating conditions that are analyzed. The program also accepts a specification for the total pressure ratio across an inlet governor valve (specify 1.0 if no inlet governor valve is to be considered).

Figure 4 illustrates the basic seal geometry employed for shrouded blades and the turbine exhaust-end seal. The fin thickness,  $t$ , pitch,  $p$ , clearance,  $\delta$ , and gap radius,  $r$ , are required as well as the number of fins. The base clearance,  $\Delta$ , is also required. This is required to compute the windage loss for rotor rows. In the case of no seal fins, it also is used to compute the leakage flow. In the case of the vertical disk seals (figure 1), the radii before and after the seal are specified and the program will calculate the seal pitch.

Figure 5 illustrates the blade-section geometry to be supplied for the various blade rows in the turbine. Program *AxTurb* is a hub-to-shroud type analysis, which requires blade geometry at a series of radii sufficient to cover the range from hub to shroud and to provide for reasonable accuracy for interpolation of the data for any radius in that range. Typically, data for about five constant-radius sections is sufficient. The data required are: blade inlet camberline angle,  $\beta_1$ , the blade gauging angle,  $\beta_g$ , the chord,  $c$ , the maximum thickness,  $t_{max}$ , the trailing edge thickness,  $t_2$ , and the suction surface curvature,  $1 / R_c$ , downstream of the throat, where  $R_c$  is the surface radius of curvature. Figure 5 defines  $\beta_g$  and provides an approximation for  $1 / R_c$  that is sometimes useful.

Partial admission turbines require specification of the fractional arc of admission (i.e., the total active arc) and the number of separate active arcs comprising the total active for all stationary blade rows. In some partial admission applications, a portion of the rotor blades are shielded on the downstream side to prevent recirculation of flow into the inactive blade passages. This is specified as a fractional shielding relative to the total 360-degree arc).

Sections I through IX summarize the input geometry specifications required for a performance analysis with program *AxTurb*. Supply specifications for the components applicable to your case only. For multistage turbines copy as many blade row specification forms as you need to supply geometry for all blade rows.

**I. Specify The Units Used For These Specifications.**

Length: \_\_\_\_\_ Temperature: \_\_\_\_\_ Pressure: \_\_\_\_\_

**II. Basic Turbine Specifications:**

These specifications permit including an inlet control valve pressure drop and an exhaust loss coefficient to permit an estimate of an exhaust diffuser influence on overall performance. Omit these specifications if not needed.

Turbine Inlet Governor Valve Total Pressure Ratio: ----- \_\_\_\_\_

Turbine Exhaust Loss Coefficient ----- \_\_\_\_\_

**III. Turbine Upstream Seal Leakage (Diaphragm-Disk Construction Only):**

- Check Option:  Ignore Seal Leakage  
 Use Computed Data At First Station As Seal Upstream Conditions  
 Specify Seal Upstream Pressure & Temperature

Upstream Pressure: ----- \_\_\_\_\_

Upstream Temperature: --- \_\_\_\_\_

**IV. Turbine Downstream (Exhaust Seal) Leakage**

- Check Option:  Ignore Seal Leakage  
 Use Following Exhaust Seal Specifications:

Downstream Pressure: ----- \_\_\_\_\_

Downstream Temperature: ---- \_\_\_\_\_

Seal Clearance: ----- \_\_\_\_\_

Number of Seal Fins: ----- \_\_\_\_\_

Seal Pitch: ----- \_\_\_\_\_

Seal Point Thickness: ----- \_\_\_\_\_

Seal Radius: ----- \_\_\_\_\_

**V. Turbine Computing Stations And End-Wall Geometry**

Specify the end-wall geometry for all computing stations in the following table (copy it if you need more stations than the table provides). Stations should be specified before and after all blade rows to provide accurate flow data into and out of the blade row (i.e., two stations between blade rows are recommended). Additional stations can be specified as considered appropriate. However, there is little benefit from specifying more than one station upstream of the first blade row nor more than one station after the last blade row. The analysis at stations with no blade row upstream is totally inviscid flow analysis, which has virtually no effect on performance unless the station is









