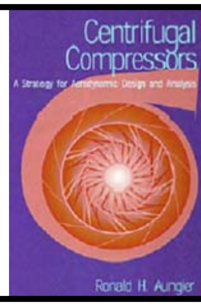
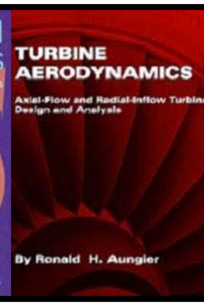
TURBOMACHINERY AERODYNAMICS CONSULTING

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





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Subject: Input Geometry Required for Constructing a Blade Passage Using Program *RIGPAC*

References: Aungier, R. H., ***Centrifugal Compressors: A Strategy for Aerodynamic Design and Analysis*** (ASME Press, New York, 2000).

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

Program *RIGPAC* (the Radial Impeller Geometry Package) is a general geometry program for blade passage design. It is most often used for impellers for centrifugal compressors and radial-inflow turbines but is applicable to virtually any turbomachine vaned component. Often it is the most efficient way to convert the impeller geometry data available to conduct a performance analysis for centrifugal compressors (program *CENCOM*) or radial-inflow turbines (program *RIFT*). This is particularly true when the available data is from reverse engineering. Even in other cases, its ability to compute parameters that may be very hard to estimate (e.g., blade angles, throat area, etc.) may favor its use. Program *RIGPAC* can generate all impeller geometry input data required by programs *CENCOM* and *RIFT*. It is often easier to provide the impeller geometry to this program than to the performance analysis programs.

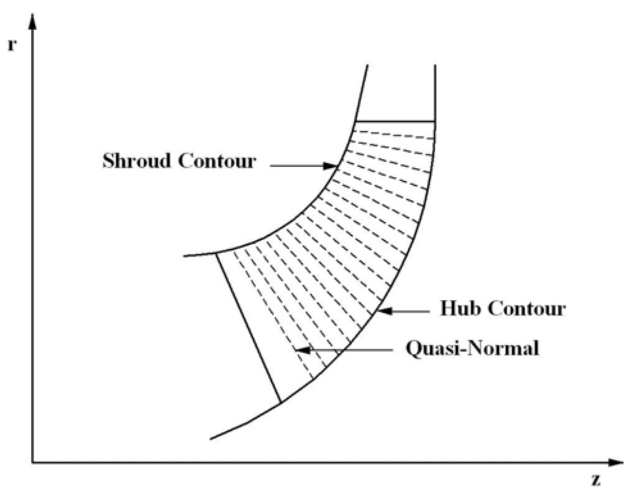

Figure 1: Contours and Quasi-Normals

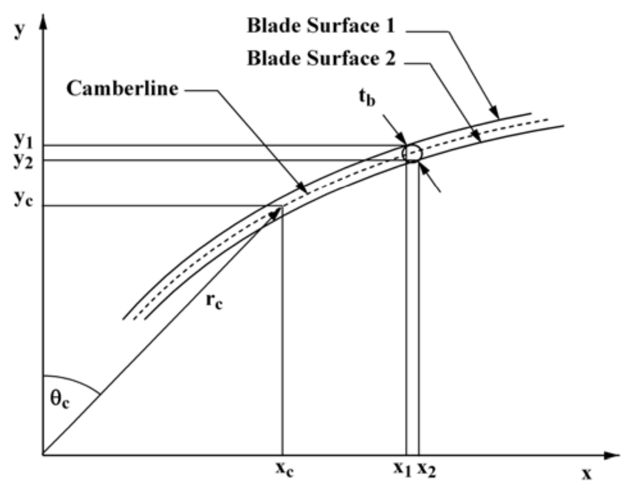

Figure 2: Blade Coordinates

Figures 1 and 2 illustrate the basic geometry data required. The program can construct three commonly used blade types: three-dimensional straight-line element (ruled surface) blades, two-dimensional axial line-element camberline blades and two-dimensional radial line-element camberline blades. For ruled surface blades, blade geometry is required on both the hub and shroud surfaces. For the other two types, blade geometry is specified along the longest surface (typically the hub surface) and the contour (z, r) coordinates of the other surface are supplied. Note that this basically restricts the program to full-inducer impellers when radial line-element blades are used.

For ruled-surface blades, the blade coordinates supplied on the two surfaces should define the surface line elements that define the blade. For reverse-engineered blades, the end points of the line elements used by the designer may not be known precisely. Also, it is usually difficult to pair corresponding surface measurements to reasonably approximate the local blade thickness. Usually that blade type employs camberline line elements that are approximately normal to both the hub and shroud contours, commonly called quasi-normals, as illustrated in figure 1. Lacking other information, that is usually the best assumption to use when reverse engineering the blades. Using points approximately equal spaced along each end-wall contour is usually equally acceptable. Program *RIGPAC* accepts geometry for the blade camberline along with the corresponding blade thicknesses or blade coordinates for the two blade surfaces at the end-points of the line elements. Usually it is not practical to obtain blade surface coordinates precisely on the end-wall contours due to the presence of a fillet radius or a clearance gap. That is not a major problem since program *RIGPAC* needs only the line-element definition so long as the actual end-wall contour is known. Hence, blades defined by the surface coordinates should also be supplemented by (z, r) coordinates for the actual contours of the end-walls. Those coordinates simply define the contours and need not correspond to points where the blade surface coordinates are supplied. Program *RIGPAC* can impose those definitions of the end-wall contours and extend the blade surface line elements to intersect them. That is usually a good practice for reverse engineered cases, since the blade surface coordinates may not yield a particularly good estimate of the end-wall contour and its blade camberline. That feature can also be used to impose alternate end-wall contours when alternate impellers are derived from simple shroud flow cuts on the basic impeller geometry.

It should be emphasized that program *RIGPAC* is not specifically intended for reverse-engineering data reduction. It works well in that role if the blade surface point coordinates are supplied as matched pairs that yield a reasonable approximation of the local blade thickness. Some processing of the measurements may be necessary to provide data that achieves a reasonable approximation from paired points on the two blade surfaces.

Program *RIGPAC* was originally developed for centrifugal compressor impellers, so it works in a compressor orientation, such that the blade passage throat is always at the blade inlet. It has provision to reverse the flow direction to allow treatment of radial-inflow turbine components as well, so its compressor orientation is not a real limitation, but it must be recognized when supplying geometry for radial-inflow turbines.

In summary, the following geometry input data are normally required:

- Three-dimensional, ruled surface blades require blade coordinates for both the hub and shroud contours. For greater accuracy, the precise hub and shroud contours should also be defined if practical, particularly if the blade data are not supplied precisely on those contours.
- Two-dimensional blades require the blade coordinates along the end-wall contour that defines the longest blade (usually the hub contour) and the end-wall contour (z, r) data for the other end-wall. Again, specification of the precise end-wall contour geometry for the end-wall where blade data are supplied may be wise for reasons discussed for the three-dimensional blade.

There are several options for supplying the blade data as illustrated in figures 1 and 2. The available options and the section numbers of the following pages to supply the geometry are:

- Section I: hub Cartesian coordinates for blade surface points (x_1, y_1, z_1) and (x_2 ,y_2, z_2).
- Section II: shroud Cartesian coordinates for blade surface points (x_1, y_1, z_1) and (x_2, y_2, z_2).
- Section III: hub camberline Cartesian coordinates (x_c ,y_c, z_c) and blade thicknesses, t_b.
- Section IV: shroud camberline Cartesian coordinates (x_c ,y_c, z_c) and blade thicknesses, t_b.
- Section V: hub camberline cylindrical coordinates (z_c ,r_c, θ_c) and blade thicknesses, t_b.
- Section VI: shroud camberline cylindrical coordinates (z_c ,r_c, θ_c) and blade thicknesses, t_b.
- Section VII: hub and/or shroud contour (z, r) coordinates.

Supply only those data sets required for your impeller per the above discussion. Supply as many points as necessary to adequately define the blade or end-wall contour (typically, around twenty points from inlet to discharge are quite sufficient). Note that for three-dimensional ruled surface blades, the number of blade coordinates supplied on the hub and shroud must be identical. If more convenient, an Excel spreadsheet can be used to supply the data, following the same format.

The origin of the axial coordinate, z, is arbitrary but must be consistent for all data sets. Program *RIGPAC* can also use values of z defined in the opposite direction from that shown on figure 1 if that is more convenient. The polar angle, θ_c, (figure 2) is in degrees and $-180 \leq \theta_c \leq 180$ is required. The length units are arbitrary (note: *RIGPAC* can scale all lengths if your source of data is in different units or from a different scale size than the actual impeller). It is fairly common for end-wall contour and blade drawings to be referenced to different axial locations such that the origin (z = 0) may differ. This may also occur in data from reverse engineering. Program *RIGPAC* can make adjustments for that for you. Hence, each of the data set sections allow you to assign an axial shift (Δz) to be imposed on all z values supplied, such that a common z origin is used for all data sets (so that you don’t have to correct them all manually).

I. **Hub Blade Surface Coordinates:**

(Optional) Δz = ____________

x_1	y_1	z_1	x_2	y_2	z_2

II. Shroud Blade Surface Coordinates:

(Optional) Δz = ____________

x_1	y_1	z_1	x_2	y_2	z_2

III. Hub Blade Camberline Cartesian Coordinates and Thicknesses:

(Optional) Δz = ____________

x_c	y_c	z_c	t_b

IV. Shroud Blade Camberline Cartesian Coordinates and Thicknesses:

(Optional) Δz = ____________

x_c	y_c	z_c	t_b

V. Hub Blade Camberline Polar Coordinates and Thicknesses:

(Optional) Δz = ____________

z_c	r_c	θ_c	t_b

VI. **<u>Shroud Blade Camberline Polar Coordinates and Thicknesses:</u>**

(Optional) Δz = ____________

z_c	r_c	θ_c	t_b

VII. <u>Hub and/or Shroud Contour (z, r) Coordinates:</u>

(Optional) Hub Δz = _____________ (Optional) Shroud Δz = _____________

Hub Contour Data		**Shroud Contour Data**	
z	**r**	**z**	**r**