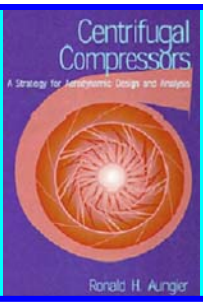
TURBOMACHINERY
AERODYNAMICS CONSULTING

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



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Subject: Input Geometry required for a Centrifugal Compressor Aerodynamic Performance Analysis Using Program *CENCOM*.

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

The geometry specifications required for a centrifugal compressor aerodynamic performance analysis with Program *CENCOM* are described in the following pages. Supply geometry only for those components that are actually included in the stage. Any geometry not known must be estimated, which may compromise the prediction accuracy. Multistage compressors require geometry for all of the stages to be included.

I. Specify the Units Used for the Input Data and the Stage Inlet Type

`Length` __________ `Velocity` __________ `Pressure` __________ `Temperature` __________

Inlet Type (Check One): ________ Single Stage (Nose-Spinner)
________ Multistage (Return channel expected upstream)
________ Inlet Guide Vanes (see X, below)
________ Inlet Passage (see IX, below)

II. Impeller Geometry

The basic geometry for the impeller passage is illustrated on figures 1 and 2. Impeller blade geometry is supplied on axisymmetric surfaces defined by the appropriate streamline (hub, mean or shroud). This requires some care when specifying the blade angles. The mean streamline corresponds to the average annulus area location. Typically, this corresponds to radii defined by the root-mean-square of the corresponding hub and shroud radii. A reasonable level of approximation in defining the mean streamline is acceptable and often may be necessary when a complete three-dimensional CAD model is not available. Since blade geometry is required at only a few locations, this can usually be handled without major hardship. The major requirement is to provide accurate estimates of the blade angles and blade thicknesses at the leading and trailing edges and the throat area. Sometimes it is easier to supply impeller geometry data for Program *RIGPAC*, which can create the impeller portion of the input file for Program *CENCOM*.

Cover tip diameter, d_C, (zero for open impeller) -------------- ______________

Disk tip diameter, d_D, -- ______________

Housing rms surface finish ------------------------------------ ______________

Shroud (open impeller) or cover clearance, δ_C, ----------------- ______________

Disk clearance, δ_D, -- ______________

Blade inlet hub diameter, d_{1H}, --------------------------------- ______________

Blade inlet shroud diameter, d_{1S}, ------------------------------ ______________

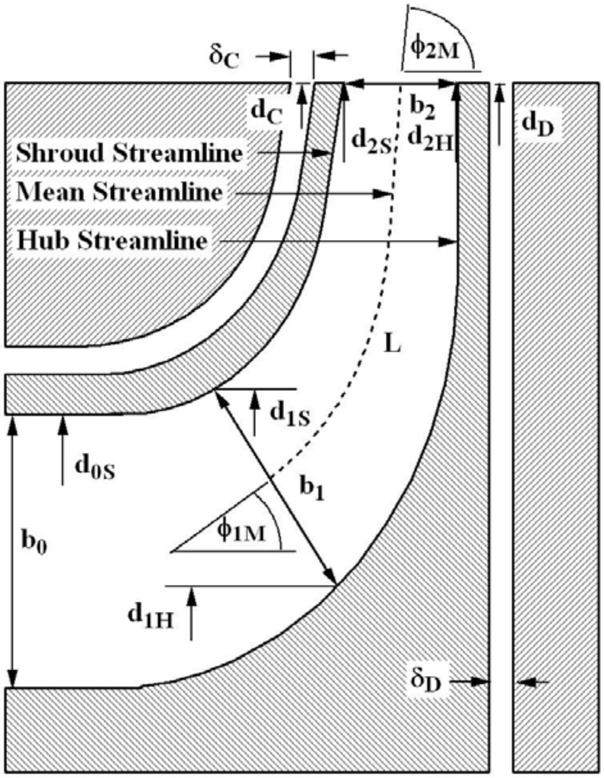

Figure 1: Basic Impeller Geometry

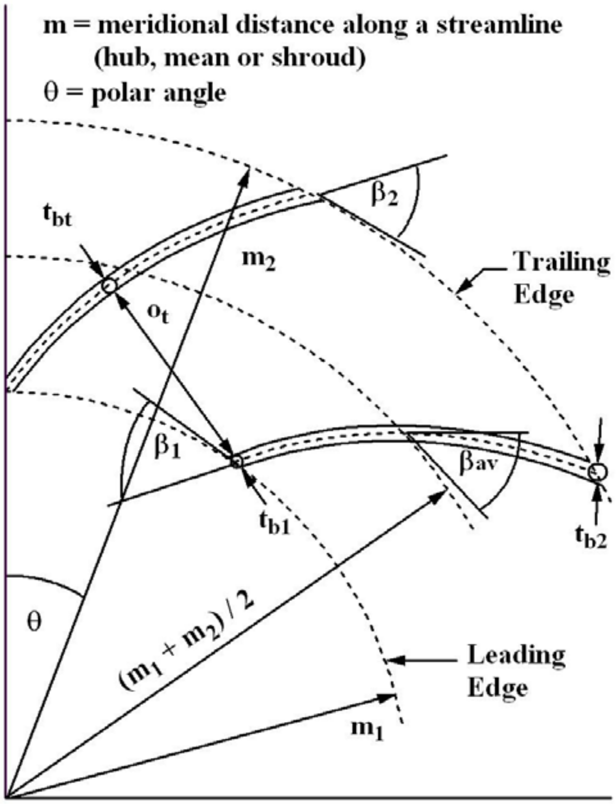

Figure 2: Impeller Blades in a Streamline Surface

Inlet mean blade angle, β_1, ------------------------------------ ____________

Inlet hub blade angle, β_{1H}, ------------------------------------ ____________

Inlet shroud blade angle, β_{1S}, --------------------------------- ____________

Inlet passage width, b_1, --------------------------------------- ____________

Blade discharge hub diameter, d_{2H}, ----------------------------- ____________

Inlet mean blade thickness, t_{b1}, ------------------------------- ____________

Inlet mean streamline slope angle, ϕ_{1M}, ------------------------ ____________

Inlet fillet blockage (fraction of gross area) ---------------- ____________

Blade discharge shroud diameter, d_{2S}, -------------------------- ____________

Discharge mean blade angle, β_2, -------------------------------- ____________

Discharge passage width, b_2, ---------------------------------- ____________

Discharge mean blade thickness, t_{b2}, --------------------------- ____________

Discharge mean streamline slope angle, ϕ_{2M}, -------------------- ____________

Discharge fillet blockage (fraction of gross area) ------------ ____________

Total number of full-length blades ---------------------------- ____________

Total number of splitter blades ------------------------------- ____________

Meridional length of full-blade mean streamline, L, ----------- ____________

Meridional length of splitter-blade on the mean streamline ---- ____________

Impeller internal rms surface finish -------------------------- ____________

Mid-passage mean blade angle, β_{av}, ----------------------------- ____________

Impeller (total) throat area ---------------------------------- ____________

Eye diameter, d_{0s} (optional, for thrust calculation) ----------- ____________

Eye passage width, b_0, (optional, for thrust calculation) ------ ____________

III. Seal Geometry

Shaft and cover labyrinth seal geometry (figure 3) is optional (leakage is ignored for seals where it is not supplied). Of course, cover seal geometry is not supplied for open impellers. If relevant seal data are omitted, the program does not supply an impeller thrust calculation, since the pressure distributions along the disk and the cover can be strongly influenced by seal leakage and significantly influence the impeller thrust. The program can complete seal leakage calculations for cover seals and shaft seals in return channel stages from the basic geometry. You will need to supply some specification of the shaft seal discharge pressure and temperature for cases not involving a return channel, since the analysis can not supply that information so it must be approximated and entered as input. For example, shaft seal exit data for a single stage volute machine often can be specified as identical to the stage inlet conditions. If needed, supply guidance under comments below.

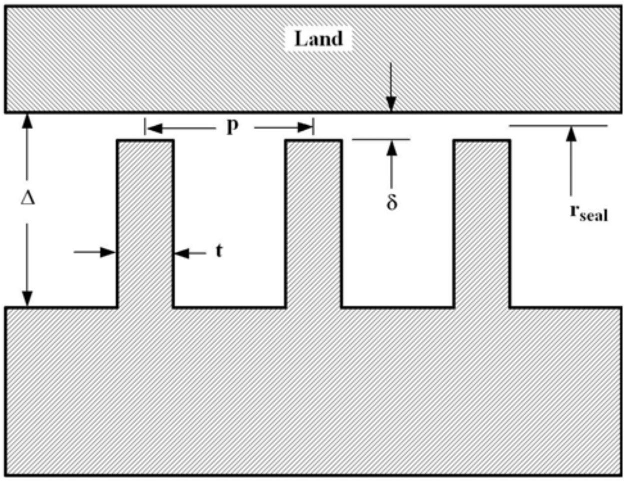

Figure 3: Seal Geometry

Number of cover seal fins, N, --------------------------------- ____________

Cover seal pitch, p, -- ____________

Cover seal point thickness, t, -------------------------------- ____________

Cover seal clearance,δ, -- ____________

Cover seal diameter, 2 x r_{seal}, --------------------------------- ____________

Number of shaft seal fins, N, ---------------------------------- ____________

Shaft seal pitch, p, --- ____________

Shaft seal point thickness, t, --------------------------------- ____________

Shaft seal clearance, δ, --------------------------------------- ____________

Shaft seal diameter, 2 x r_{seal}, --------------------------------- ____________

Comments: ____
____
____
____

IV. Vaneless Diffuser Geometry (Or Vaneless Passage Upstream Of A Vaned Diffuser)

Vaneless diffuser geometry is entered at a sufficient number of points along the passage to allow reasonable approximation by interpolation from the points supplied. The data supplied are the axial coordinate, z, (the origin is arbitrary) radius, r, passage width, b, and the angle between a tangent to the mean streamline and the axial direction, ϕ. Often, these passages have a significant section where z and b vary linearly with radius, usually with constant ϕ. If that is applicable, enter the first and last radius of that section as negative numbers to indicate the start and end of a linear section. Enter as many points as necessary for reasonable interpolation (outside of any linear sections).

Passage rms surface finish ------------------------------------ ____________

z	r	b	ϕ

V. Vaned Diffuser Geometry

The nomenclature for the vaned diffuser geometry is illustrated in figure 4. The subscripts 3 and 4 designate inlet and discharge stations (i.e., the vane leading and trailing edges. These should be defined at the center of the vane "nose radius", i.e., they are just inside the vane passage. The vaneless space between the impeller and vaned diffuser should be supplied as a vaneless diffuser. Similarly, any vaneless space downstream of the vaned diffuser should be supplied as a vaneless space as described subsequently in section IX. Program *CENCOM* models conventional airfoil style vaned diffusers, but has been found effective for vane-island diffusers also on a number of applications. It can be used for low solidity vaned diffusers also, but in that case the throat width, o_t, must be defined by connecting the leading and trailing edge surfaces on adjacent blades, since there is no true throat. It is not highly recommended for that application, but it has been found to yield reasonable results in the limited number of cases considered.

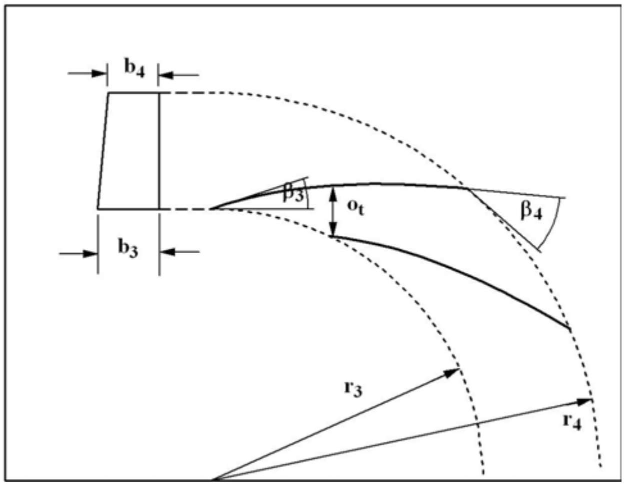

Figure 4: Vaned Diffuser Geometry

Vane inlet mean radius, r_3, ------------------------------------ ____________

Inlet mean vane angle, β_3, ------------------------------------- ____________

Inlet passage width, b_3, --------------------------------------- ____________

Inlet mean vane thickness, t_{b3}, --------------------------------- ____________

Vane discharge mean radius, r_4, -------------------------------- ____________

Discharge mean vane angle, β_4, --------------------------------- ____________

Discharge passage width, b_4, ----------------------------------- ____________

Discharge mean vane thickness, t_{b4}, ----------------------------- ____________

Blade passage throat width, o_t, -------------------------------- ____________

Vane angle at mid-passage, β_{av}, --------------------------------- ____________

Blade Passage rms surface finish ------------------------------ ____________

The number of vanes --- ____________

VI. Crossover (Return Bend) Geometry

A crossover bend is approximated by two elliptical shaped end-walls as shown on figure 5. You simply supply specific passage widths and values for appropriate ellipse axes or semi-axes.

Inlet (and discharge) radius, r_5, ------------------------------ ____________

Inlet passage width, b_5, --------------------------------------- ____________

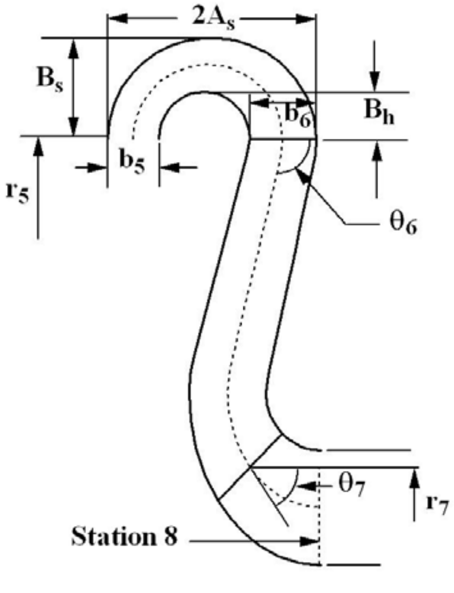

Figure 5: Crossover & Return Channel Geometry

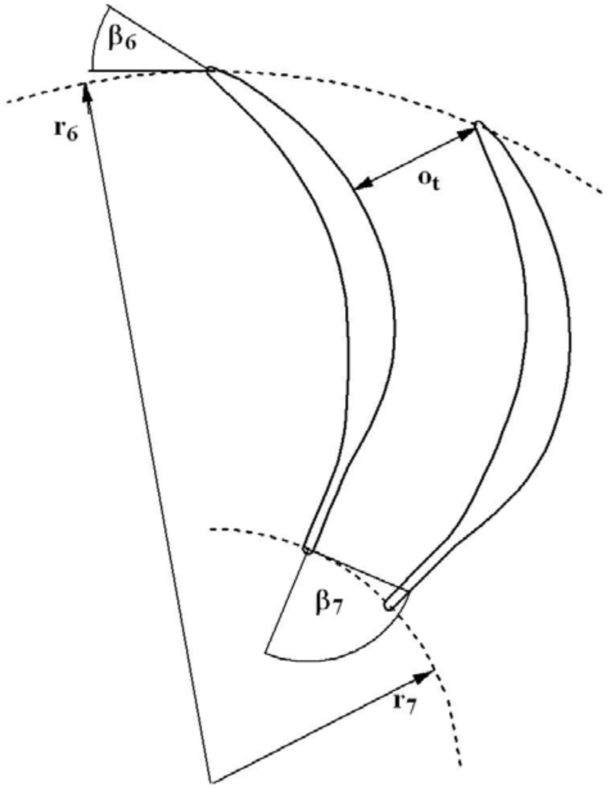

Figure 6: Return Channel Vane Geometry

Discharge passage width, b_6 ------------------------------------ _____________

Shroud ellipse axial major-axis, $2A_s$ --------------------------- _____________

Hub ellipse radial semi-axis, B_h, ---------------------------- _____________

Shroud ellipse radial semi-axis, B_s --------------------------- _____________

Passage rms surface finish ------------------------------------ _____________

VII. Return Channel Geometry

The nomenclature for the return channel geometry is shown on figures 5 and 6. Often the return channel vane leading edge may be below the crossover discharge radius. In that case, a vaneless passage should be inserted between the crossover and return channel (see section IX, below). Several mean streamline slope angles with the axial direction are used to account for passage curvature effects. Note that these angles will normally be negative or zero. The slope angle at station 8 is not shown on figure 5 since it is zero as is normally the case.

Blade inlet mean radius, r_6, ----------------------------------- _____________

Inlet mean blade angle, β_6, ------------------------------------ _____________

Inlet passage width, b_6, --------------------------------------- _____________

Inlet mean blade thickness, t_{b6}, --------------------------------_____________

Blade discharge mean radius, r_7, ------------------------------- _____________

Discharge mean blade angle, β_7, -------------------------------- _____________

Discharge passage width, b_7, ----------------------------------- _____________

Discharge mean blade thickness, t_{b7}, --------------------------- _____________

Blade passage throat width, o_t, -------------------------------- _____________

Blade angle at mid-passage, β_{av}, -------------------------------- _____________

Vane inlet streamline slope angle, θ_6, ------------------------- _____________

Vane exit streamline slope angle, θ_7, -------------------------- _____________

Passage exit streamline slope angle, θ_8, ----------------------- _____________

Blade Passage rms surface finish ------------------------------ _____________

Number of blades -- _____________

VIII. Volute Geometry

The volute geometry required is identical for either a scroll or a constant area collector. Figure 7 illustrates the geometry for a scroll. The same nomenclature is used for a collector. The mean passage radius, r_6, and passage area, A_6, is required at the circumferential location where all of the flow has been collected (the full-collection plane). The area at the volute exit, A_7, may be required, to include an exit cone. Omit this parameter if there is no exit cone. The inlet radius, r_5, and the inlet passage area, A_5, are obtained from the last component analyzed upstream of the volute. The mean radius, r_m, and area, A_m, at the circumferential location where 50% of the flow has been collected are optional input parameters if they do not conform to normal volute or collector design practice. Usually they can be omitted. By default the program will assume they are identical to r_6, and A_6 for a collector if they are not specified. For a scroll, r_m is assumed to be the average of r_5, and r_6 and A_m is assumed to be half of A_6 if they are not specified.

Specify the type (scroll or collector): ____________________

Full-collection plane area, A_6, -------------------------------- __________

Full-collection plane radius, r_6, ------------------------------ __________

50%-collection plane area, A_m, (optional) ---------------------- __________

50%-collection plane radius, r_m, (optional) -------------------- __________

Exit cone discharge area, A_7, (optional) ----------------------- __________

Passage rms surface finish ------------------------------------ __________

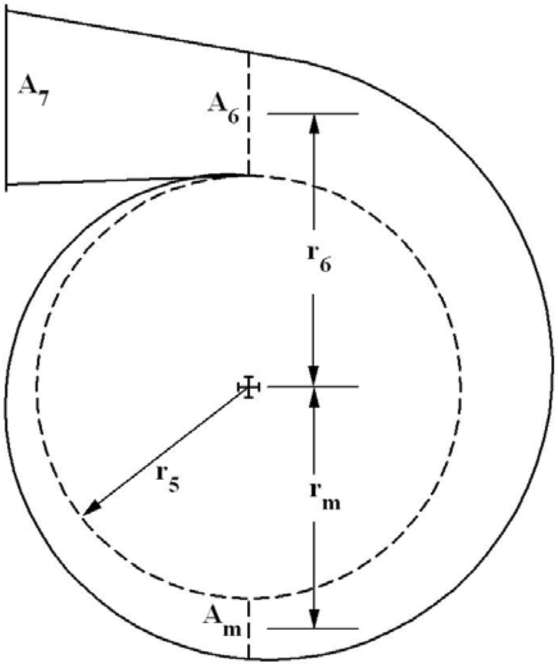

Figure 7: Volute Geometry

IX. Vaneless Passage Geometry

It is often necessary to include various annular passages located between the other major components to model a complete stage. Provision for three vaneless passages is made here, which is usually more than sufficient. But additional vaneless passages can be included if needed (simply copy the next page as many times as needed). The input data for these components is identical to that for the vaneless diffuser as described previously. The only difference from the vaneless diffuser input is that you need to specify where it is located in the stage so it can be inserted in the proper location (e.g., “upstream of the crossover,” “upstream of volute,” “upstream of the impeller,” etc.). The passage inlet and discharge geometry should match to the geometry of the adjacent components were applicable. However, the program can account for abrupt changes in passage width at the vaneless passage inlet when applicable (i.e., abrupt area expansion or contraction losses can be accounted for at the entrance.

Vaneless Passage #1

`Specify the location:` ____________________

`Passage rms surface finish -----------------------------------` __________

z	r	b	ϕ

Vaneless Passage #2

`Specify the location:` ____________________

`Passage rms surface finish -----------------------------------` __________

z	r	b	ϕ

Vaneless Passage #3

Specify the location: ____________________

Passage rms surface finish ---------------------------------- ________

z	r	b	ϕ

X. Inlet Guide Vane Geometry

Inlet guide vane geometry uses the same nomenclature as the impeller as shown on figures 1 and 2. The blade camberline angles supplied are for the specific vane setting and must be changed for each setting in the case of adjustable vanes. Specifying alternate discharge vane camberline angles, β_2, at the end is sufficient.

Inlet mean passage radius, r_1, -------------------------------- ________

Inlet vane camberline angle, β_1, ------------------------------ ________

Inlet (total) passage annulus area ---------------------------- ________

Vane camberline angle at mid-passage, β_{av}, ---------------------- ________

Passage meridional length, L, ---------------------------------- ________

Discharge mean passage radius, r_2, ---------------------------- ________

Discharge vane camberline angle, β_2, -------------------------- ________

Discharge (total) passage annulus area ------------------------ ________

Specify any other vane setting angles to be analyzed (specifying values of β_2 only is sufficient):

____

____

____

____

____

XI. Intercooler Data

An intercooler can be specified but must be the first component in the stage in which it appears. The program does not actually analyze intercoolers, but does allow you to incorporate your cooler performance specification into the analysis to properly account for it in the compressor performance analysis. The exit total temperature is given by

$$T_{out} = \underline{\hspace{2cm}} \times T_{in} + \underline{\hspace{2cm}}$$

Usually the exit temperature is controlled, which can modeled by setting the first field to zero and the second field to the exit temperature. But the more general specification can be used if appropriate. The pressure drop across the intercooler can be specified directly as a pressure drop or by a loss coefficient. In the latter case, a flow passage area must also be specified so the program can perform a mass balance to determine the velocity pressure ($P_v = P_t - P$) to which the loss coefficient multiplier is to be applied. Sometimes it is necessary to perform a liquid knockout or equilibrium flash calculation after an intercooler. This can be done if the working fluid has at least two components (e.g., air and water vapor) and it is to be modeled as a non-ideal gas mixture.

$$P_{out} = P_{in} - \underline{\hspace{2cm}} \times P_v - \underline{\hspace{2cm}}$$

Passage area (if needed): ______________

Check if an equilibrium flash is needed _______

XII. Specified Total Pressure Loss Data

The program also accepts total pressure loss specifications to account for losses not modeled directly (e.g., special piping arrangements, etc.). The specification is similar to the one used for intercoolers, but allows different loss coefficients for the meridional and tangential dynamic heads to be specified and uses the local velocity pressure upstream of the insertion point rather than basing it on an area specification. You also need to specify the location (e.g., between stages 1 and 2, upstream of the volute, at the end of the compressor, etc.). If α is the upstream flow angle with tangent, the loss data specification is (enter zero for portions not used)

$$P_{t,new} = P_t - \underline{\hspace{2cm}} \times P_v \sin^2\alpha - \underline{\hspace{2cm}} \times P_v \cos^2\alpha - \underline{\hspace{2cm}}$$

Location: ____

XIII. Extraction Flow Data

The program can impose an extraction flow at the end of the stage to extract a portion of mass flow from the compressor for use elsewhere. This corrects the flow on any subsequent stages in a multistage analysis and predicts the extraction flange pressure required. Specify the ratio of the extraction mass flow to the compressor mass flow, the extraction passage loss coefficient and the passage area used to calculate the velocity pressure associated with the loss coefficient definition (see intercooler, above). The loss coefficient is applied in the same form as for intercoolers. The extraction flow discharge flange area, the compressor passage area and its mean radius after the extraction are also required.

Extraction-to-stage mass flow ratio: ____________________

Extraction discharge flange area: ____________________

Extraction flow Loss Coefficient: ____________________

Passage area for the loss coefficient: ____________________

Final compressor discharge area: ____________________

Final compressor discharge mean radius: ____________________

XIV. Side-Load Flow Data

The program can impose a side-load flow at the end of the stage to introduce additional mass flow into the compressor for use on any subsequent stages. Specify the ratio of the side-load mass flow to the current stage mass flow, the side-load flow total temperature, the side-load loss coefficient and the passage area to be used to calculate the velocity pressure associated with the loss coefficient definition. The loss coefficient is applied in the same form as for the intercooler. The side-load and compressor areas immediately before and after mixing of the two streams are also required.

Side-load-to-stage mass flow ratio: ____________________

Side-load flow total temperature: ____________________

Side-load flow Loss Coefficient: ____________________

Passage area for the loss coefficient: ____________________

Side-load inlet flange area: ____________________

Side-load discharge area before mixing: ____________________

Stage discharge area before mixing: ____________________

Total passage area after mixing: ____________________

Passage mean radius after mixing: ____________________