<u>Centrifugal Compressor Application Studies Using the *CompAero* Software System</u>

The *CompAero* Software system provides a rather sophisticated application capability that is very useful for centrifugal compressor aftermarket applications such as rerates and revamps. This involves using the stage preliminary aerodynamic design program (*SIZE*) and the aerodynamic performance analysis program (*CENCOM*) to develop realistic stage designs and conduct a performance analysis for the intended application. Program *SIZE* develops fairly complete stage configurations that are well suited to specified performance objectives. Required input specifications are generally quite minimal, but offer sufficient generality to address the known design constraints commonly encountered in rerate activity such as shaft size, casing size, axial length, speed, flange areas, etc. Program *SIZE* can also export a complete program *CENCOM* input file to permit an immediate performance analysis of the stage configuration developed. When the required stages have been configured, program *CENCOM* can combine their input files to permit a complete multistage performance analysis. That yields a realistic estimate of achievable performance for quotation, including the expected performance map.

Recently a typical application study was accomplished as a courtesy to an organization considering a fairly comprehensive compressor rerate. That case is a rather good illustration of using *CompAero* for application work. The goal was to completely replace the internals of an available industrial centrifugal compressor casing to accomplish a totally different duty. The immediate objective was to establish feasibility, develop a basic compressor configuration and estimate the achievable performance. The specified geometrical constraints were the existing side-inlet flange area, the inner (shaft plus impeller sleeve) diameter and the outer (casing) diameter. The working fluid, compressor inlet conditions, required mass flow and discharge pressure were also specified. The approximate rpm preferred to match a turbine driver was also supplied.

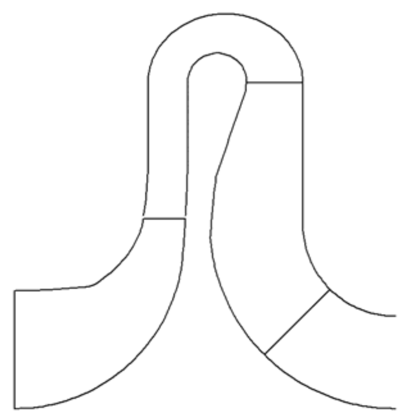

Figure 1: Stage #1 Configuration

The most critical aspects of feasibility can be evaluated by selecting the first stage using program *SIZE*. Using the above conditions and constraints, an optimum first stage was selected. Due to the rather high flow coefficient required, it was immediately obvious that the impeller diameter should be as large as practical. After two or three tries, it was found that a first stage flow coefficient of about 0.136 could be achieved while maintaining a fairly conservative impeller rotational Mach number (tip speed / inlet total sound speed) of about 0.88 and an acceptable vaneless diffuser radius ratio of about 1.48. This also resulted in a reasonable mechanical tip speed as well. This is a rather high stage flow coefficient, but flow coefficients up to about 0.15 can be achieved with a basic radial impeller (as apposed to a more complex mixed-flow impeller design). The geometry was exported to program *CENCOM* and the known inlet flange area was inserted as the stage inlet station. An estimate of the side inlet loss is also needed. As a general rule, the total pressure loss coefficient of a side inlet (based on flange conditions) can be expected to be in the range of 1 – 2. From past experience with this specific OEM's inlet designs, the loss coefficient was known to be about 1.7, which was also inserted into the analysis of the first stage as an assigned loss coefficient imposed after the inlet flange. The performance analysis showed that the inlet flange Mach number at design flow would be about 0.139. Opinions differ on the preferred upper limit for this parameter, but generally fall in the range of 0.1 - 0.15. Hence, the analysis of this first stage design indicates that this rerate should be feasible. Figure 1 is a screen capture of the stage #1 preliminary configuration developed by program *SIZE*.

The remainder of this application study was quite simple. Using the known mass flow and the discharge conditions of the upstream stage, successive stages were configured and analyzed until the required discharge pressure was achieved. At this point, discharge pressure does not need to be matched exactly, but should be matched close enough so that modest adjustments to the speed or to the work-per-stage values used can produce the required discharge pressure. It was easily shown that a four-stage compressor would be required for this duty.

As a final step, the program *CENCOM* input files for the four stages were combined by program *CENCOM* into a single (multistage) input file and an overall performance analysis was conducted. This is necessary to account for the effects of any residual whirl existing at the return channel exits (i.e., as pre-whirl to the downstream stage) and to obtain the performance estimate and associated performance maps for the multistage compressor. Due to the approximate initial sizing and residual whirl effects, the predicted discharge pressure was about 6% less than the required value. Increasing the speed by 1.4% corrected that deficiency and would be quite acceptable for this application. Alternatively, the default stage work coefficients selected by program *SIZE* could have been adjusted for that purpose. The following table shows the important performance results obtained for the four stages. Except for the rather high flow coefficient of the first stage, this is a relatively conservative aerodynamic design.

Parameter	Inlet	Stage #1	Stage #2	Stage #3	Stage #4
Cumulative Temperature Ratio	**1.0000**	**1.1888**	**1.3806**	**1.5733**	**1.7655**
Cumulative Pressure Ratio	**0.9773**	**1.6380**	**2.5719**	**3.8189**	**5.3997**
Stage Flow Coefficient	**----**	**0.1340**	**0.0973**	**0.0720**	**0.0553**
Impeller Rotational Mach No.	**----**	**0.8957**	**0.8220**	**0.7636**	**0.7163**

Figures 2 and 3 are screen captures of the performance maps generated by program *CENCOM* for the four-stage machine. Program *CENCOM* offers a variety of choices for performance map variables (work, head, discharge pressure, pressure ratio, efficiency, power, discharge temperature, temperature ratio, mass flow, volume flow, etc.) and both adiabatic and polytropic performance. The data for any of these map variables can easily be exported to Excel or graphics software if a more refined map presentation is needed for quotation. These basic performance curves show good head-rise-to-surge, surge margin, choke margin and efficiency (83% at design flow). The symbol (X) on the curves corresponds to the design flow.

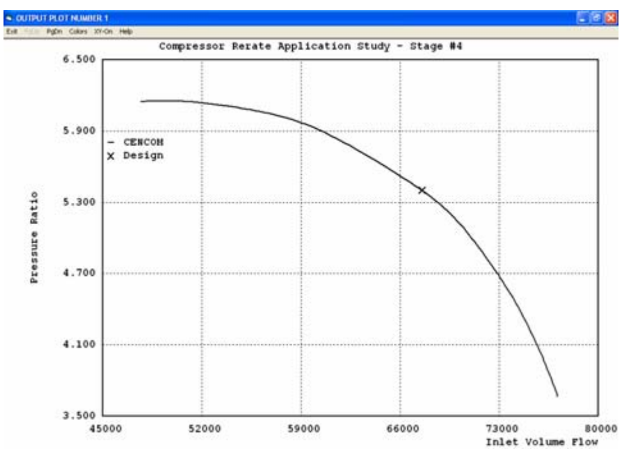

Figure 2: Pressure Ratio vs. Inlet Flow

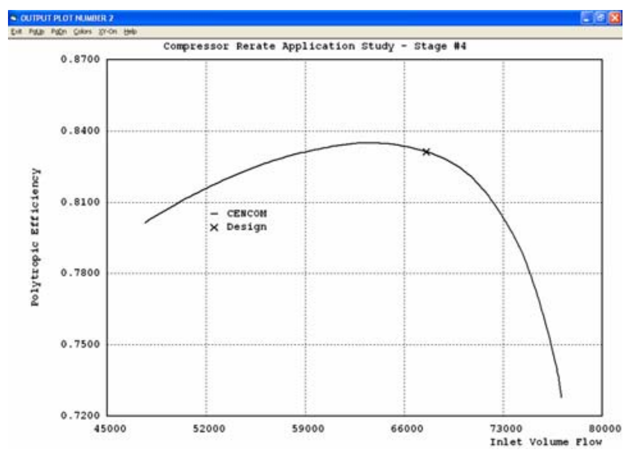

Figure 3: Polytropic Efficiency vs. Inlet Flow

This application study is sufficient to provide the aerodynamic designer with a high degree of confidence that the detailed aerodynamic design process will produce a compressor that can achieve the expected performance. While many days of detailed aerodynamic and mechanical design activity will be required to actually accomplish that, this entire application study was completed in less than an hour. Hence, the combination of programs *SIZE* and *CENCOM* provides a viable and cost-effective procedure for application engineers to establish the feasibility of a rerate, configure the stages that will be required and obtain performance estimates for a preliminary quotation.