PROPRIETARY REPORT

ADVANCED DIFFUSER PERFORMANCE FOR CENTRIFUGAL COMPRESSORS AND PUMPS

FINAL REPORT FOR THE DIFFUSER CONSORTIUM

PHASE IV

THE PERFORMANCE OF LOW-SOLIDITY AIRFOIL DIFFUSERS WITH CENTRIFUGAL COMPRESSOR STAGES AT $N_S = 55$ AND $N_S = 85$

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EXECUTIVE SUMMARY

Laboratory evaluations of low-solidity airfoil diffusers and computational fluid dynamic (CFD) evaluations for three different industrial centrifugal compressor stages, covering N_s = 55, 85, and 115, have been conducted. A principal objective for this fourth phase of the international centrifugal compressor and pump diffuser consortium was to develop the two additional (N_s = 55 and 85) test configurations complete with necessary instrumentation, workhorse impeller, and associated elements. The N_s = 55 stage was principally developed in a companion consortium (the stability consortium), whereas the N_s = 85 stage was developed totally in the present consortium. A series of baseline, low-solidity airfoil diffuser tests was conducted with each set of hardware. Comprehensive rotor validation tests were conducted for each new stage, and each was found to completely meet its design specifications. CFD calculations on each of the three rotors were conducted.

As with the earlier Phase II and Phase III investigations, the low-solidity airfoil diffuser has shown excellent stable operating range. This has been completely consistent through all phases of investigation and shows great promise for the low-solidity airfoil diffuser for widespread industrial application. For the low N_s configuration, the efficiency was improved by using a low-solidity airfoil diffuser when compared with the industry standard baseline of a pinched vaneless diffuser. For the intermediate specific speed stage, the performance was also improved over the vaneless diffuser, but this is not a relevant baseline comparison since the vaneless diffuser would not be used under the higher pressure ratio conditions of this stage. This stage awaits further tests to establish a comparative baseline of a suitable channel diffuser. Nonetheless, the N_s = 85 stage showed improved efficiency and pressure ratio by using the cascade diffuser compared with the vaneless diffuser. However, the gain in performance was less than desired. It appears that additional tests, forming a moderate matrix of design possibilities, should be conducted to further understand this performance issue.

Two alternative tests were conducted using shroud bleed. Each configuration showed improved range. One configuration showed a very satisfactory improvement in range (Fig. ES1), with a degradation of between one and three points of stage efficiency across the operating map. Of considerable importance, however, was the fact that the work input coefficient was the same whether the cover slot was present or not. The investigators believe that the cover slot can be changed significantly in the future with the hope of reducing or eliminating the efficiency penalty. The cover bleed configuration appears to be an excellent method for extending the stable operating range of centrifugal compressors by increasing both the choke and surge margins appreciably.

CFD calculations on the three different rotors showed qualitative agreement with the measured exit flow surveys. However, there were also quantitative disparities that are troublesome. Background calculations with a low-solidity airfoil diffuser showed comparatively poor agreement, and this defect may very well be traced to inadequate inlet boundary conditions, which are, in fact, unsteady in time. It is recommended that a higher level code be used for future calculations and that coupled calculations involving the rotor and stator be employed in future diffuser consortium investigations.

The results of this study have been most encouraging for future design. It is quite probable that excellent range can be designed into future stages following the lead established in this consortium. Efficiency improvements have been demonstrated for

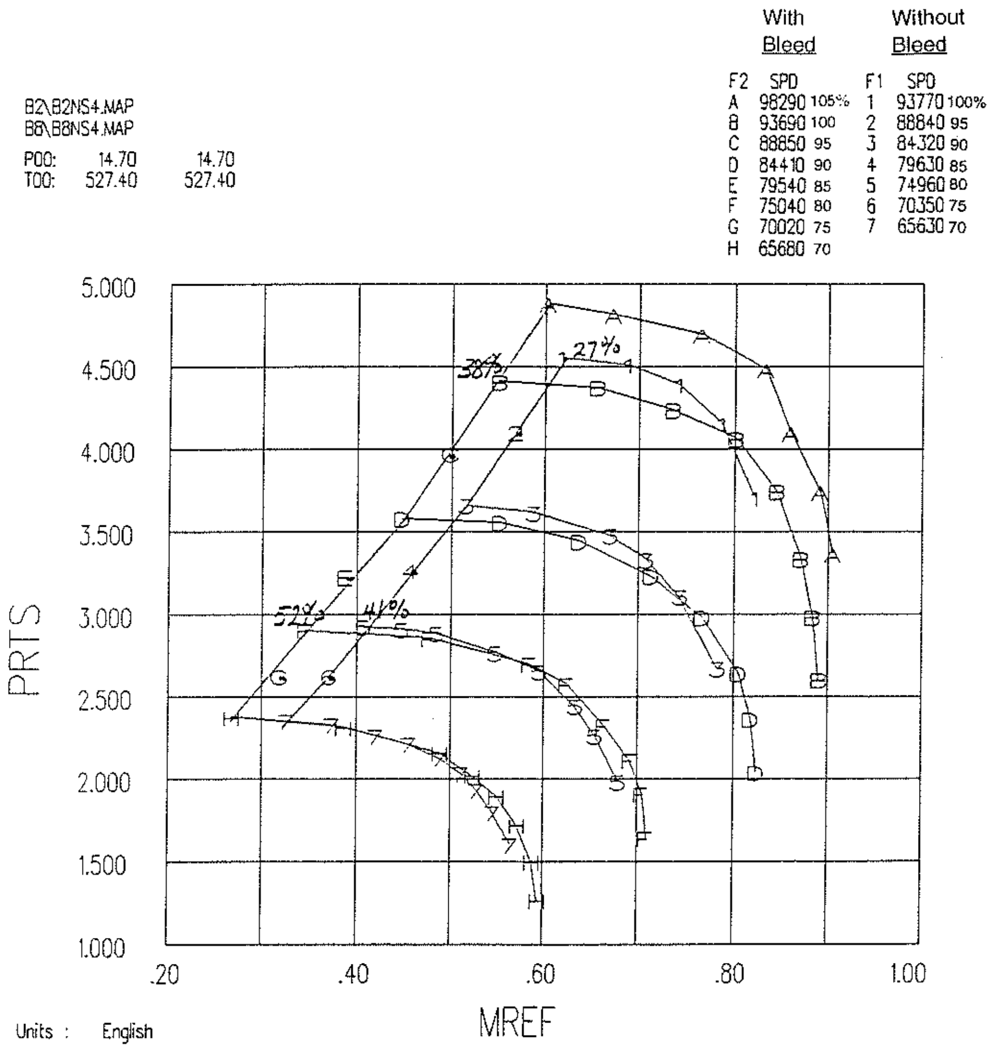

Figure ES1. Significant range enhancement was obtained with shroud bleed.

N_s = 55 and N_s = 115 through this and previous consortium phases. With further investigation, it is probable that improved efficiency and further improved range can be obtained for all design configurations. A series of recommendations has been formulated to guide the next step in this very important investigation.