CONCEPTS engineering education and technology for industry

TECHNICAL MEMORANDUM NO. 99

ADVANCED DIFFUSER PERFORMANCE FOR CENTRIFUGAL COMPRESSORS AND PUMPS

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EXECUTIVE SUMMARY

The completion of the advanced diffuser performance consortium brought together many practical design facts and several interesting performance surprises. The best performance was achieved with a closely coupled channel diffuser. Tests were carried out with the diffuser leading edge radius divided by the impeller discharge radius of $R_3 = r_3/r_2 = 1.06, 1.12$, and 1.23. The closely coupled value of $R_3 = 1.0688$ was, in fact, the optimum performing diffuser. This is contrary to much of the published literature for channel diffusers. The principal results are shown in Figs. 1a - 1e. All tests were carried out with a small (2.7 in. i.e. 68.6 mm) diameter impeller. For this very small size stage, total-to-static isentropic efficiencies between 70 and 78% were obtained for speeds running from 135,000 rpm down to 80,000 rpm. On a polytropic, total-to-total basis, the efficiencies ranged from approximately 77% at full speed to approximately 82% at part speed. The test conditions varied from subsonic through transonic operation at the highest speed.

A wide range of diffuser stagger angles is possible for optimum diffuser operation. Figure 2 displays the pressure ratio and efficiency changes over a modest range of diffuser restagger. Basically, the efficiencies form a tight envelope such that a natural progression is to be observed.

The wide range of tests conducted included various values of the leading edge radius ratio, R_3; the diffuser length to width parameter, L/W; the diffuser divergence angle, 2θ; and other facts mentioned below. There appears to be an optimum diffuser length for this stage of approximately L/W = 14 and a divergence angle optimum of approximately $7°$. The divergence angle was not a fundamental parameter for this initial project but tests were carried out both at $7°$ and $9°$ and the more classical value ($7°$) is appropriate. The range of tests also illustrated an unexpected and rather significant observation: there are many indications throughout this work of a complex coupling of the pressure fields between the diffuser and the impeller. Frequently, this coupling appears to contribute to useful performance improvements for the stage.

Tests were also conducted with a smokeshelf and with a pinched diffuser. The smokeshelf provided for an abrupt passage width enlargement past the impeller tip; the pinch provided for a reduction in passage height. The smokeshelf offered no advantage. The pinched diffuser seemed to provide a marked improvement in the diffuser performance and the overall stage pressure ratio. However, it did not appear to help the stage efficiency. The pinch was tried both from the shroud and from the hub side; pinching from the hub was distinctly better than from the shroud.

In addition, based on work in a companion project, it was possible to compare the results of the best channel diffuser with an excellent, wide range cascade diffuser. These results are also embodied in Fig. 1a - 1c. The cascade diffuser showed performance almost as good as the channel diffuser but with additional operating range on the lower speed lines. The extra operating range was limited at the maximum operating speed only by the choke of the impeller inducer. For all practical purposes, the diffusers showed the same surge line. The remarkable performance of the airfoil diffuser suggests that further attention should be given to the design of tandem airfoil diffusers in a subsequent phase of work. This could become a key to

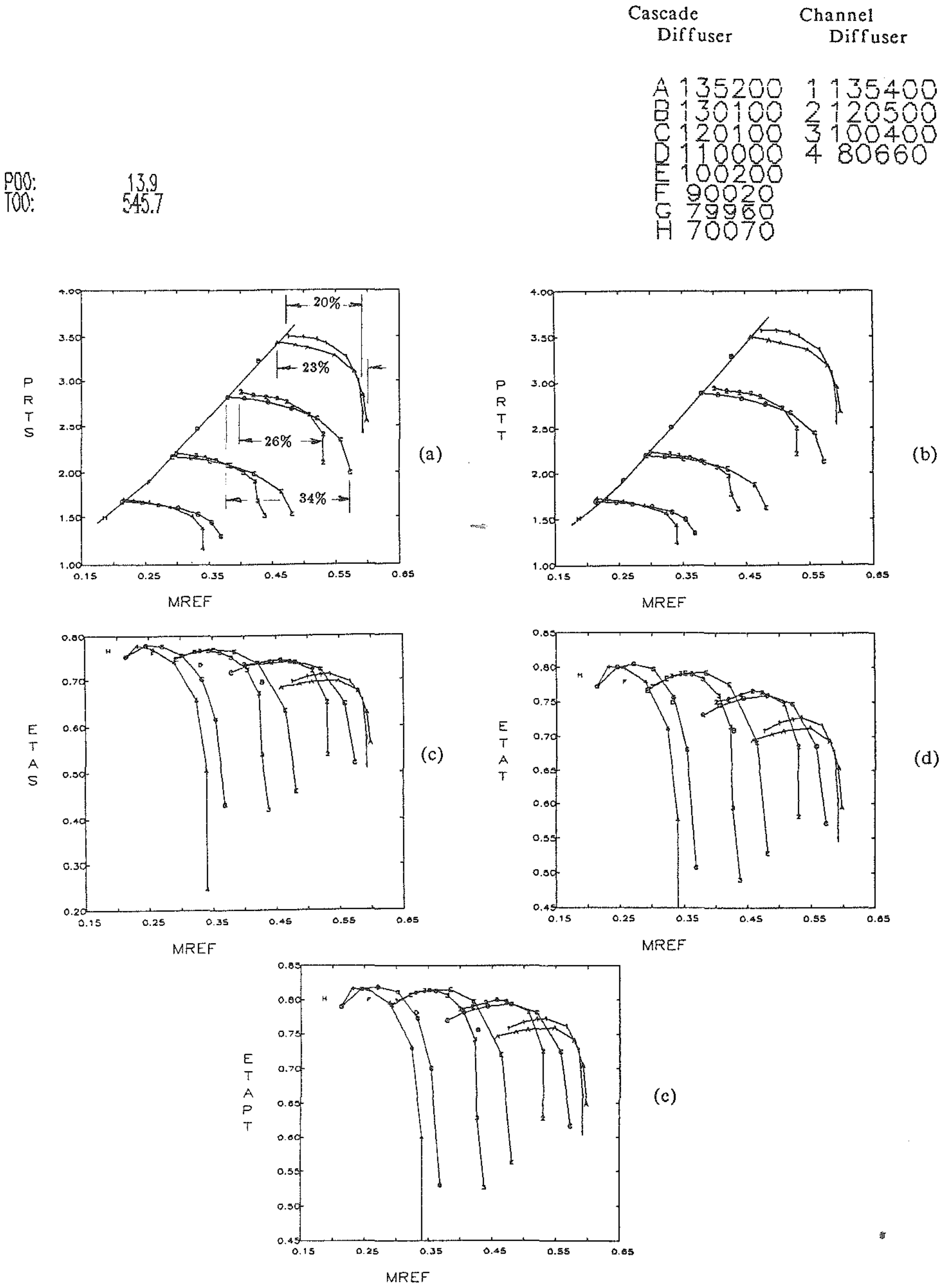

Figure 1. Comparison of Best Channel and Airfoil Diffuser Results, Based on 2.7" Diameter Rotor, Showing Peak $\eta_{poly,TT}$ from 0.77 to 0.82.

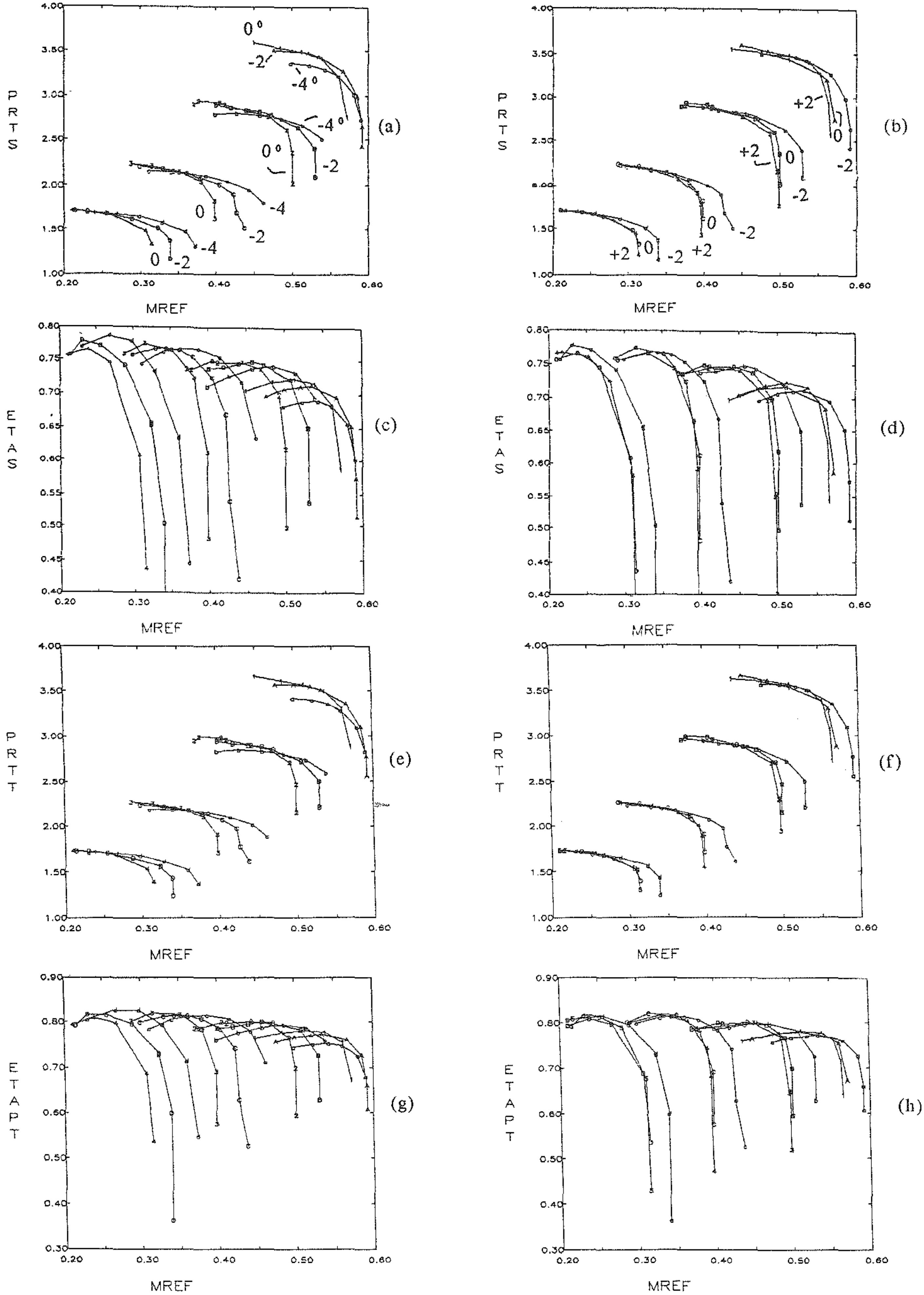

Figure 2. Comparison of best channel diffuser family (1-14+2 to 1-14-4) at various stagger angles (-2, 0, +2, +4°)

advanced industrial machinery development in the years ahead.

A fortuitous situation developed where an opportunity arose to build a larger scale model (1.88x) of the present work horse impeller and the best channel diffuser. The results for the small scale and larger scale impeller are shown in Figs. 3a - 3h. It can be observed that a significant improvement in pressure ratio and efficiency was achieved during the course of these tests. Ironically, the surge line moved to the right for the higher speed operation. This effect was completely unexpected. Basically, classical scaling seems to have prevailed in all essential characteristics except for the location of the surge line. Although not explicitly covered in this report, a similar occurrence is described briefly herein where the surge line for the small scale compressor stage moved to the right by a similar amount during the process of developing the cascade or airfoil type diffuser. It therefore appears that the surge line may be influenced by some very subtle diffuser parameters which could involve diffuser and rotor coupling. If more definitive tests can be conducted to resolve or clarify this enigma, it is likely that significant insights into enhanced stable operating range for industrial compressors might be won.

The present results have provided a wealth of data which is useful in guiding the design of advanced channel diffusers and airfoil diffusers as well. Based on a careful review of the original project scope, which called for additional phases of work past the present completed phase, it is clear that this work should continue. Further work is necessary to conclude the investigation on channel diffusers; additional work should be performed to check the effect on scale from the small scale to larger scale test facilities and substantial work should be done to optimize the tandem airfoil diffuser system.

Comprehensive results are presented in the sections which follow. This material should be carefully reviewed by each sponsor and used in future development projects wherever applicable.

P00: 13.9
T00: 545.7

Build and Speed

U_2 ft/s	1-14-2 Small	1-14-2 Large
1590	A	--
1414	B	1
1304	--	2
1178	C	3
1061	--	4
942	D	5
709	--	6

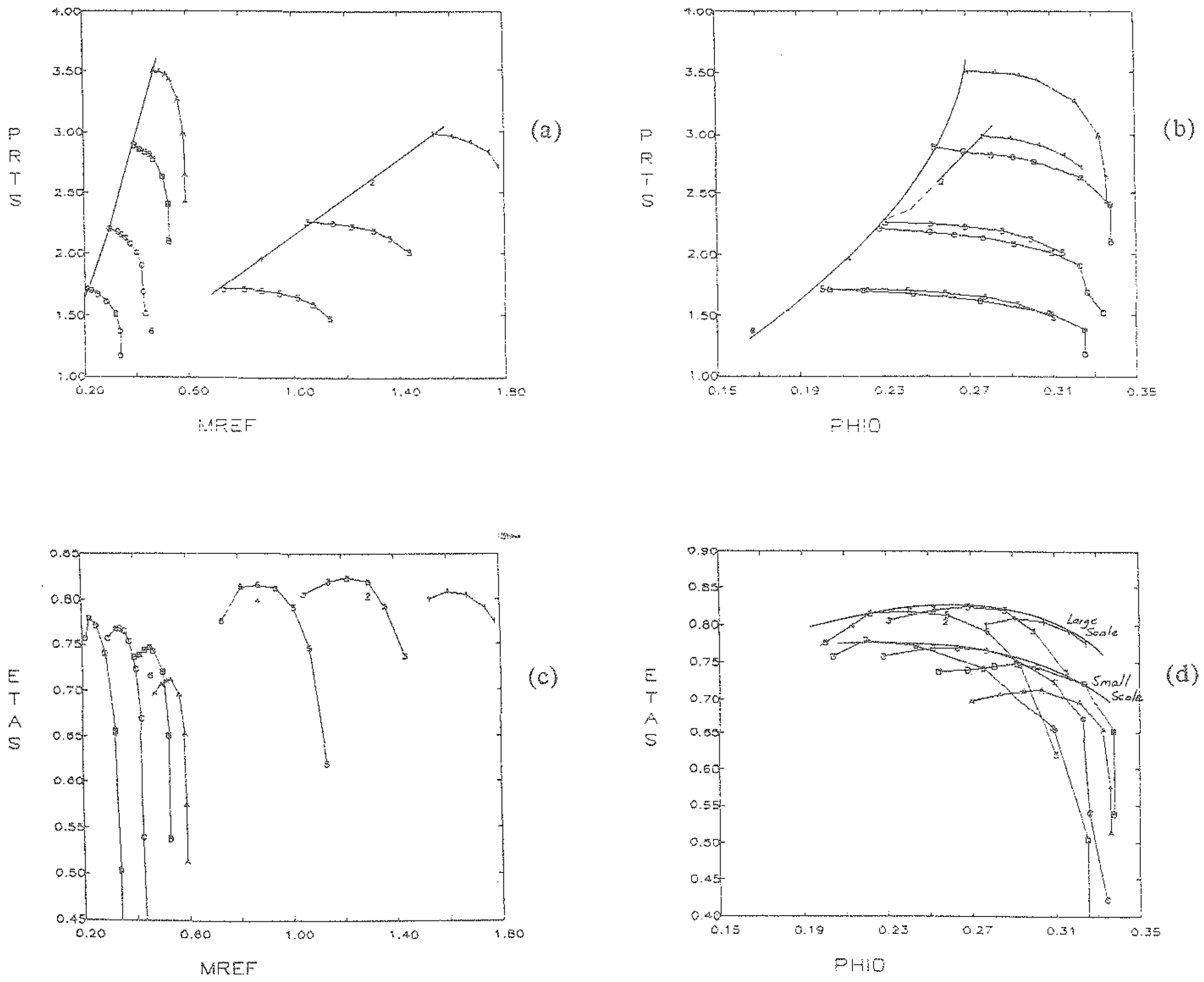

Figure 3. Comparison of small scale and large scale 1-14-2 (best channel) stage results, using mass flow and inlet flow coefficient for comparison. The loss of range for large scale is unexplained.

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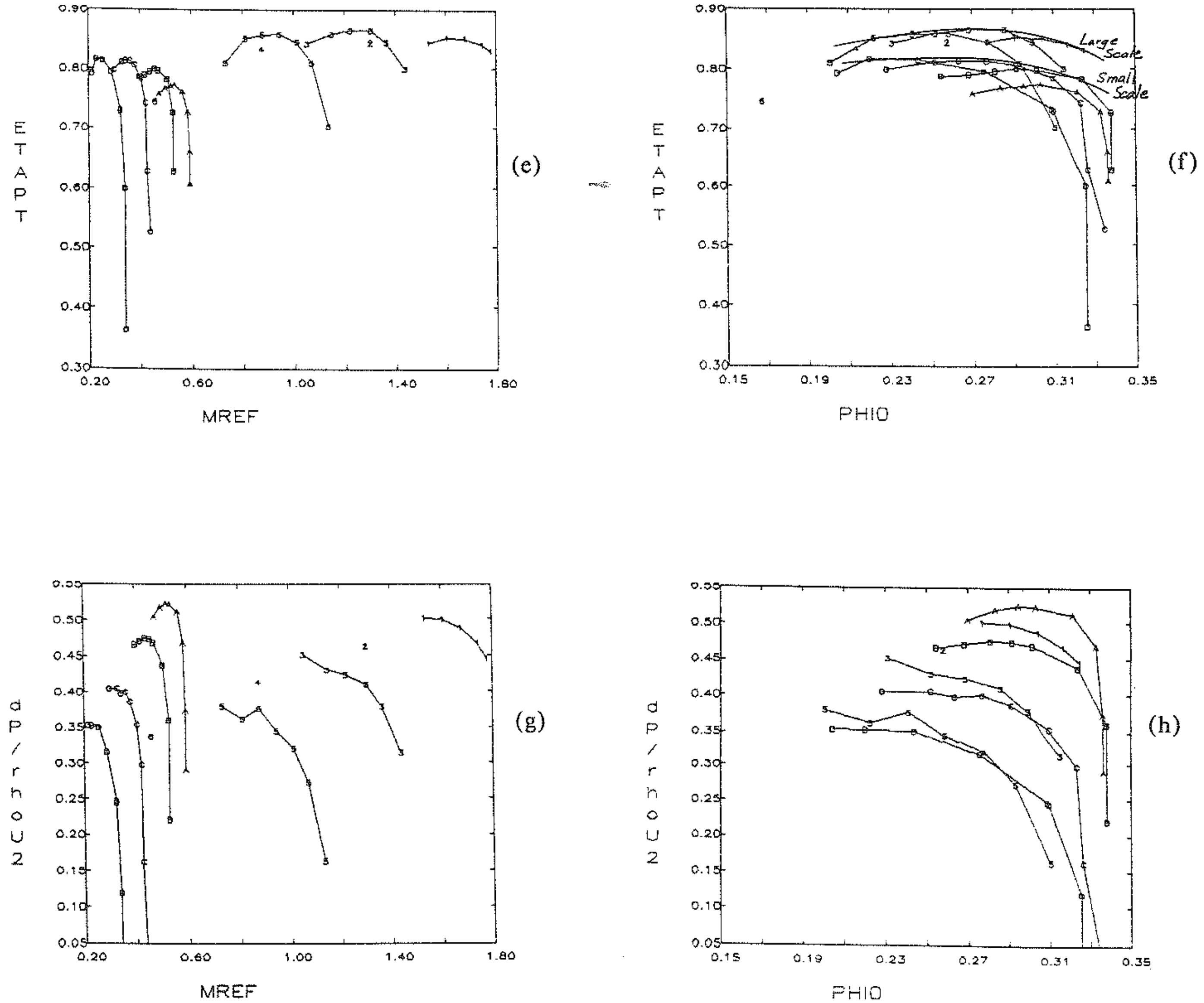

Figure 3 (concluded). Comparison of small scale and large scale 1-14-2 (best channel) stage results, using mass flow and inlet flow coefficient for comparison. The loss of range for large scale is unexplained. Figures g and h display the diffuser pressure rise, dp, divided by $\rho_{00} U_2^2$.