Concepts NREC
The Experts in Turbomachinery

NEW!! PHASE VII • ADVANCED CENTRIFUGAL PUMP and COMPRESSOR CONSORTIUM for DIFFUSER & VOLUTE DESIGN

Starting Date: June 16, 2015

Proposal Number P14887

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1.0 INTRODUCTION

Concepts NREC (*CN*) announces the seventh phase of the Advanced Centrifugal Pump and Compressor Consortium for Diffuser & Volute Design. The success of this project, through six important previous phases, plus the stability consortium as well, has created a strong basis for continued work on 1) vaneless, 2) low-solidity high-performance airfoil (LSA) and flat-plate, 3) channel, and 4) conical diffusers.

Phase VI work has focused on strategies to extend operating range and to approach or exceed 80% recovery (through several phases of work) for compressor or pump diffusers. The sixth phase extended our fundamental understanding of the basic physics of best diffusers from prior work with more detailed testing and CFD. Major breakthroughs have occurred in understanding coupling, distortion, and the control of the impeller exit profiles. A new invention was patented and demonstrated to change the impeller exit profiles and the work input by using flow-wise grooves along the stationary cover adjacent to the impeller.

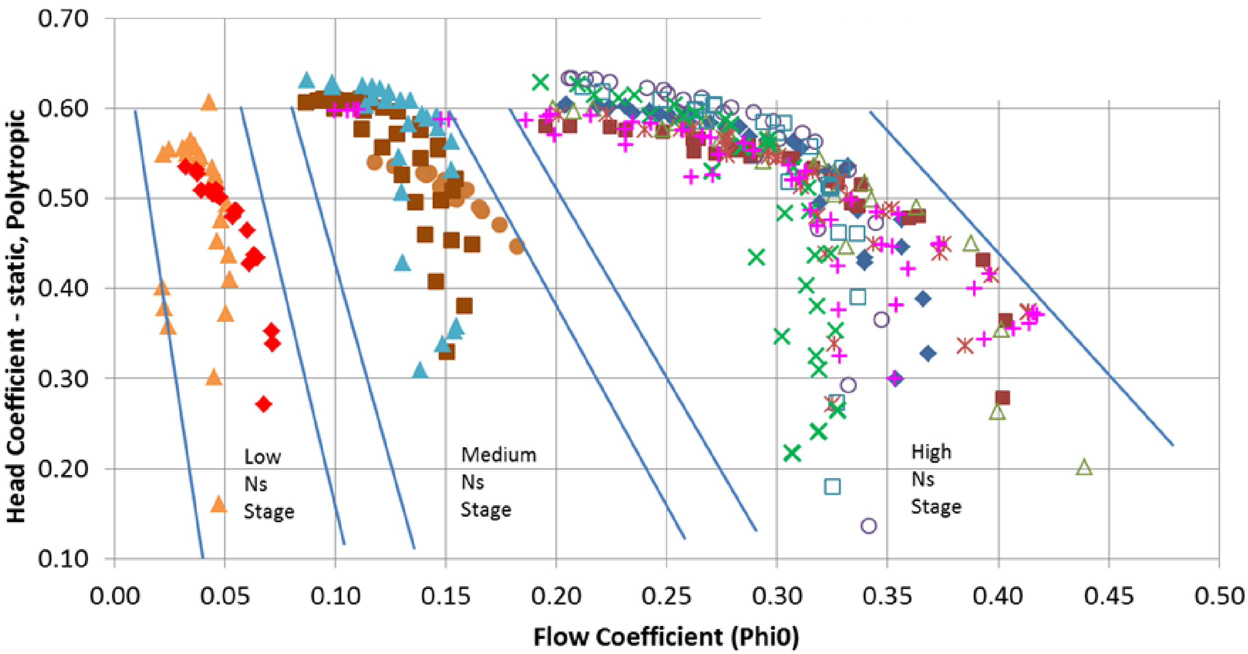

Figure 1. Psi vs. Phi for the current range of all explored stages (Phases I - VI)

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The scope of work for Phase VII proposes to expand the past work by using three (3) different rigs covering a wider range of operating conditions. The domain mapping of these stages is shown in Figure 1. In a later phase of work, we may add some of the earlier NREC stage designs to the Figure 1 coverage as well. The high Ns stage/rig will continue to be used for specific scoping tests, while the medium and low specific speed rigs will be used to extend the best diffusers to a wider range of design and operating conditions. At the end of this effort, we expect to have good baselines for each class of diffuser across a wide range of flow coefficient and head coefficient. Additionally, the novel grooved cover will be applied across the range for higher diffuser recovery and wider stable operating range. New developments covering distortion, periodicity, coupling, and flow control will be pursued deeper and exploited wherever possible.

Special attention has been given to vaneless diffusers, which are ubiquitous in the compressor field, and their significance has grown as each phase of work has progressed. Designers using this class of diffuser should note the specific comments given throughout.

1.1. Phases I – VI: Prior and Current Diffuser Consortium Work

Phase I focused mainly on channel diffusers, for a total of 23 builds covering a variety of leading edge radius ratios, impeller to diffuser vane height ratios, diffuser divergence angles, diffuser length to width ratios, and stagger angles. Performance for the channel diffuser was very high, while the airfoil (cascade) diffuser demonstrated remarkable performance and efficiency, as well as very good range. Phase I sponsorship, over time, included 33 company divisions and is applicable to boiler feed pumps, barrel pumps, heavy diesel turbochargers, gas turbines, air compressors, blowers, and many other areas. Pump users should interpret all the compressor plots herein with care: the same diffusers have invariably been found to work as good or better in pumps, except that they can often be operated further to the left on the flow characteristic than the stability or surge lines shown in the figures herein. These stability limits, however, may play a real role in pump stability for very high head applications.

Two out of 22 Phase I test builds were with a vaneless diffuser. These tests showed a strong influence of the rate of pinch on stage performance and work input, which led to deeper subsequent study. Flow field traverse surveys were conducted with two vaneless diffuser configurations. The vaneless diffuser shows very wide range for pr < ca. 2.5; for pr > 2.5, the LSA shows better stable operating range.

Phase II obtained further high levels of channel diffuser performance, excellent tandem airfoil diffuser performance, and even greater low-solidity airfoil diffuser performance. Remarkably similar high pressure ratio (head rise) and efficiency were achieved with all three diffuser types, but only the low-solidity airfoil (LSA) diffuser gave the very wide operating range *with* high efficiency and pressure ratio (see Figures 2 and 3). During Phase II, a novel characteristic of the performance of low-solidity airfoil diffusers was discovered and patented, and the IP rights became available to all participants (total of 29 sponsors). In addition to the application areas above, this technology has seen use in turbochargers, industrial compressors, and some volute pumps. Through Phases I and II, a quality, broad design database for channel diffusers resulted. Phase II also established a good tandem diffuser approach, which is valuable for bent diffusers.

Six out of 25 test builds for Phase II used a vaneless diffuser. These tests showed a very strong effect of the chosen side for and degree of pinch, and the rear pinch showed superior performance.

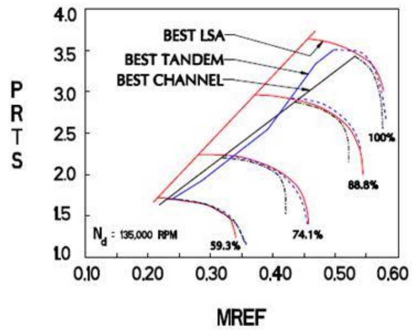


Figure 2. Best Diffusers

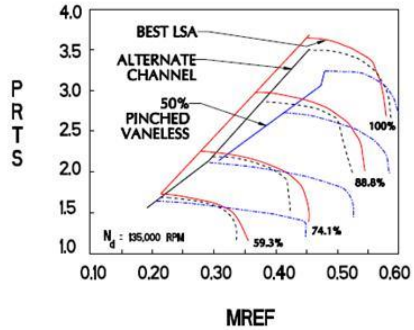


Figure 3. Alternates

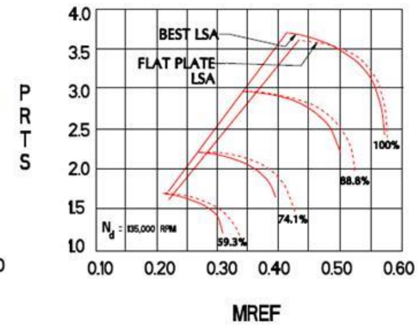


Figure 4. Flat-plate

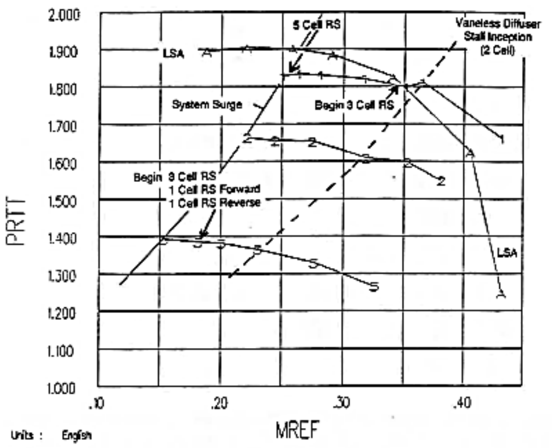
Phase III investigations included a test matrix of different values of airfoil diffuser cascade exit to inlet radius ratios, cascade lift coefficients, cascade inlet radius to impeller exit radius ratios, airfoil solidity, and airfoil shapes, including flat-plate diffuser vanes (see Figure 4). The flat-plate diffuser became a focus of great interest among sponsors. These test results were just as successful as the preceding two phases of work. Additionally, detailed traverses were carried out at the exit of the cascade diffuser and at the exit of the subsequent vaneless element. Improved loss coefficients were correlated for future design guidance. Throughout these three phases of work, a significant compendium of information was collected, which has guided a number of industrial designs for commercial application. Phase III had a total of 25 sponsors and produced technology that applies across all areas of pumps and compressors. This phase established a very good design database for airfoil diffusers.

Two out of 35 tests in Phase III were with vaneless diffusers; this included exhaustive traversing of the important rear pinch vaneless diffuser case.

Phases IV and V brought in two alternate impellers and a wide range of confirming and investigative tests. Both a low-speed industrial two-dimensional (2D) stage (pr = 1.8) and a higher pressure (pr = 4.5) medium specific speed stage were added to the test array. Confirming tests established the breadth of the earlier research results. The first applies to barrel pumps and compressors, and the second applies to high head products.

Phase IV testing included six configurations for the Ns = 85 stage and 4 configurations for the Ns =55 stage. Of the first six, 1 was a vaneless diffuser. The vaneless diffuser for Ns = 85, pr = 4.5 shows wide range for pr < ca. 2.5; for pr > 2.5, the LSA shows better range compared to the vaneless.

For the Ns = 55 covered impeller, there is a *very large* additional database, including stall maps and traverse data *for the vaneless diffuser* behavior. It has been released into the Diffuser Consortium controlled access data website; Figures 5 and 6 are exemplars. For Phase V, another 6 tests were run.



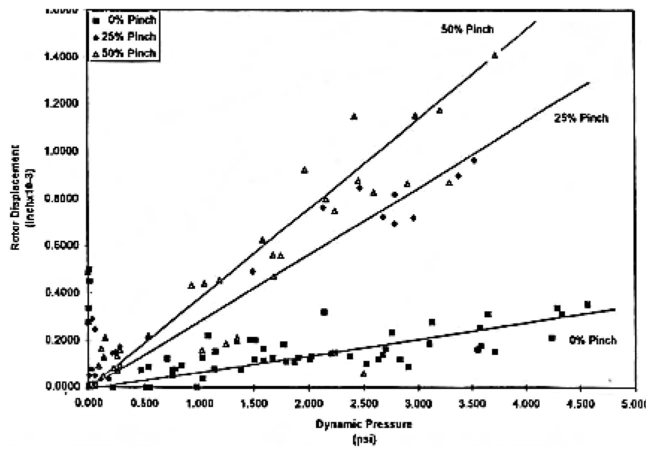


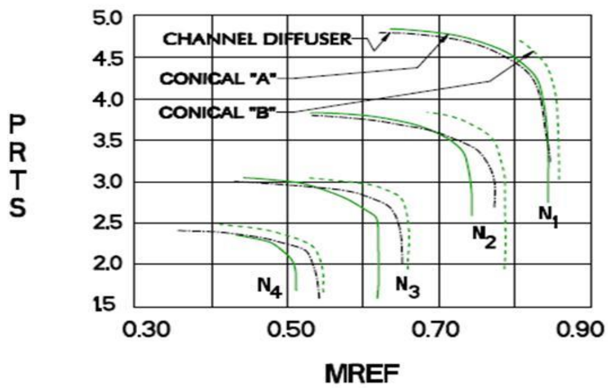
Figure 5. Pr = 1.8 stage vaneless and LSA diffuser performance – the LSA shows greater stable operating range

Figure 6. Effect of diffuser pinch on shaft vibration displacement with rotating stall present; a penalty is paid for excessive pinch

Figure 7. Consortium Impellers: [1] – High N_s; [2] – Medium N_s; [3] – Low N_s. The remaining (Nos. 4 – 6) are low N_s pump impellers comparable to item [3]

The impellers used in Phases I – V are shown in Figure 7. Even though Impeller 1 is small (Ns = 110), it gave very good diffuser performance with all the real-world challenges of larger stages; it is a powerful and fully proven workhorse for useful industrial research and development, and it is comparatively economical to operate. Impeller 2 (Ns = 85) has a pr = 4.5 and has higher Mach number characteristics, whereas Impeller 3 (Ns = 55) is a low specific speed stage with pr = 1.8.

Several *CN*-related programs have also contributed to the collection of valuable diffuser development information with the consortium impellers. Figure 8 shows the results of the second consortium impeller (pr = 4.5) with the consortium channel diffuser, as well as two conical diffusers. Due to circumstances outside of *CN*'s control, the diffuser leading edges were mismanufactured (external source), but the test results were still quite encouraging and provide a bit more information about this critical world of performance. This diffuser gave us the highest efficiency and pressure ratio for this stage, even though the range was compromised.



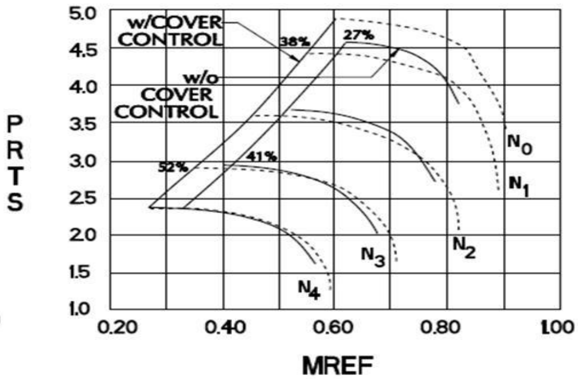


Figure 8. Conical and channel results using pr = 4.5 impeller

Figure 9. Early tests with the pr = 4.5 stage, with and without cover control range extension

Figure 9 shows tests conducted in Phase V with cover flow control. Stable operating range increased from 27% to 38%, with a slight loss in efficiency; subsequent work at *CN* has improved this picture considerably. Tests with cover control may also be part of future investigations.

The bent diffuser work shown in Figure 10 was also a related *CN* study, using the first consortium impeller (pr = 3.5), and shows that it is possible to bend the diffuser without any loss in pressure or efficiency. This is vital for some volute studies; some sponsors have suggested continuing this work into volute studies, and one such device is a very compact system with the volute packaged tight around and below the bent diffuser for a compact and economical system.

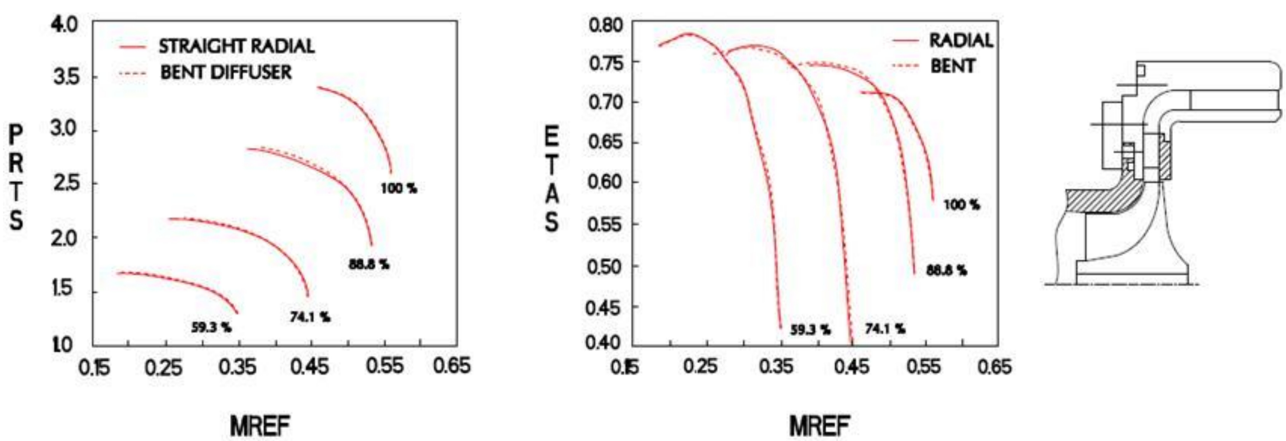


Figure 10. Related bent diffuser tests showing no adverse impact

In the Phase VI work, certain unique performance questions, especially concerning Impeller 1 above, were undertaken for resolution. Figure 11 shows the evolution of this impeller as used in Phases I – VI, including the current variant which is a precision, totally flank-milled impeller which matches the detailed measurements of the previous progenitor impeller.

Production Casting Progenitor from a Production Casting Flank Milled Replica

Figure 11. Evolution of the precision test stage

Phase VI, which concludes on June 15, 2015, extended our understanding of the core physics of best diffusers from prior work with more detailed testing and CFD. Deep insights were gained in understanding distortion, coupling, and the control of the impeller exit profiles. While coupling is not fully understood even yet, it is clear that it is frequently active and has certain distinct characteristics. Unexpected circumferential distortion has been found in a very accurate test rig and now has been retrospectively identified in five different test facilities. Hence questions of periodicity have been raised. A new invention was patented and demonstrated to change the impeller exit profiles by using flow-wise grooves along the stationary cover adjacent to the impeller. Increased stable operating range and increased pressure rise have been demonstrated. A comprehensive review of the Phase VI results is summarized in a supplementary document.

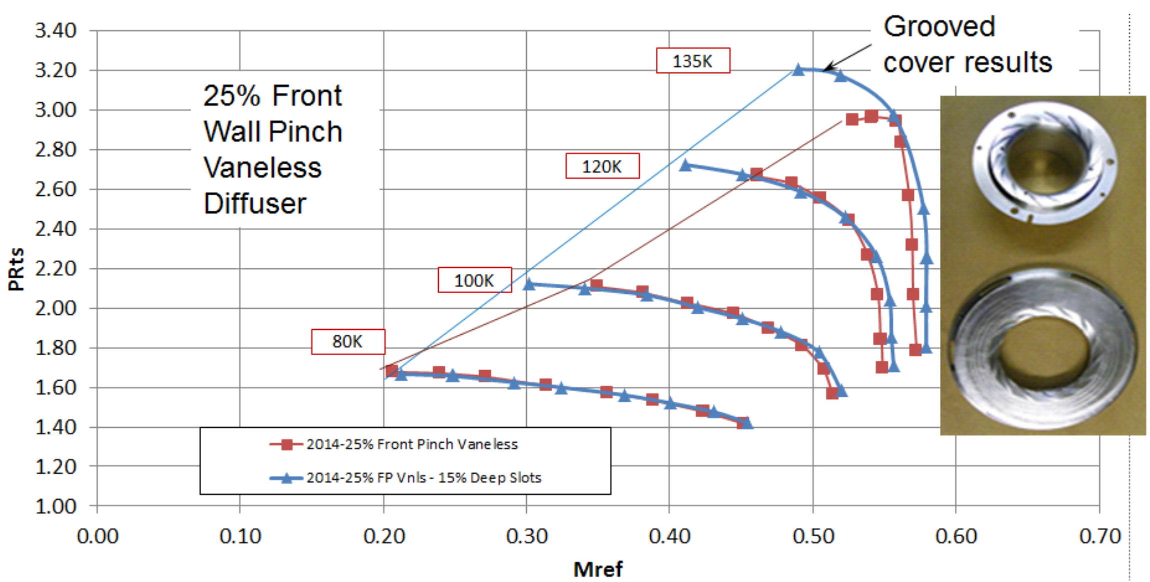


Figure 12: Enhanced performance with original flow-wise grooved cover for a *vaneless* diffuser application; 25% front pinch; US Patent 8926276B2; others pending. All Phase VI participants will receive a formal license to use this patent; *CN* rights in this technology will be firmly protected.

CFD studies have been important throughout the Phase VI investigations and will play an increased role in Phase VII. A major portion of the Phase VI Final Report is given to key lessons learned from CFD studies. For example, much of the differences between the front and rear pinched vaneless diffuser performance was sensibly predicted; see below.

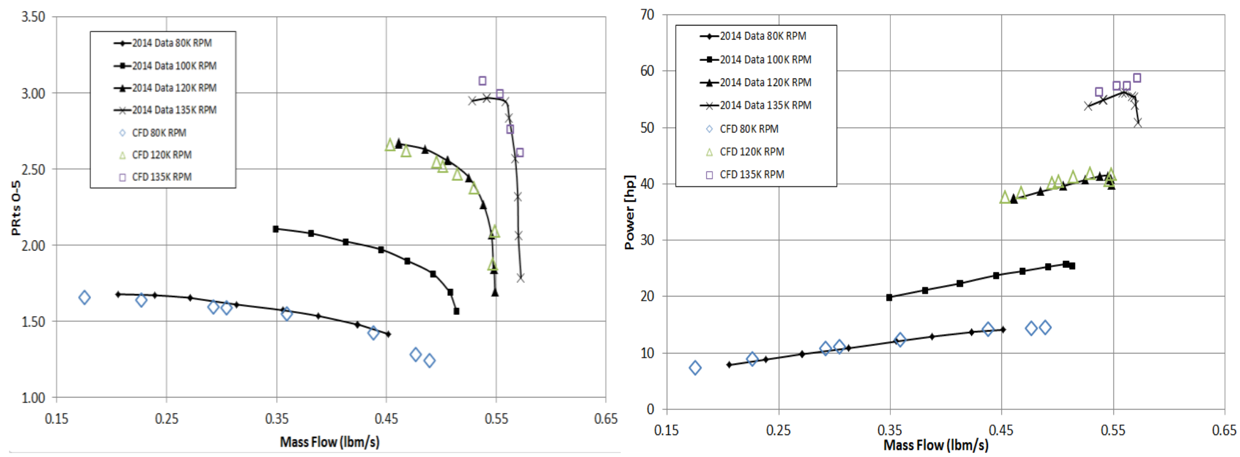


Figure 13. CFD and measured data for vaneless diffuser 25% front pinch case

CFD calculations for this reference stage have been compared to traverse data. Key results are shown in Figure 14. Full setup and data copies are now in use by consortium sponsors to make their own comparison calculations.

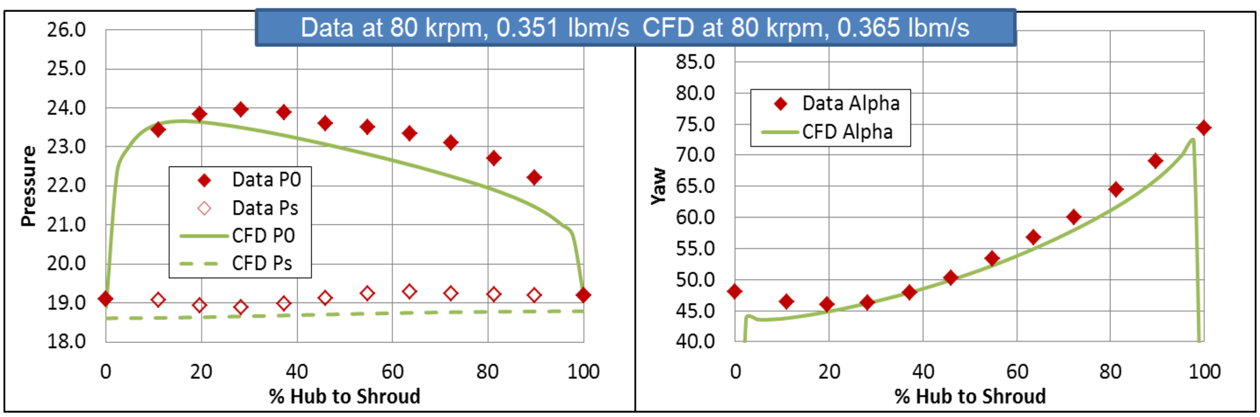


Figure 14. CFD and traverse data for the vaneless diffuser 25% rear pinch case

2.0 CRITICAL RESEARCH CHALLENGES & PAYOFF

Much has been learned, yet there is much still to be discovered. The chart below lays out a matrix of what has been tested and what remains to be done. Phase VI work concentrated only on filling in the top line of the chart with greater depth of instrumentation; the next two rows came from Phases IV and V and need continued evaluation, which many sponsors have been requesting. The items highlighted in yellow on Table I are good targets for more opportunity and will be reviewed with sponsors in the months ahead. CFD has proven to be a very valuable research tool, and its usage should be increased. Nonetheless, the grooved cover was verified even without any comprehensive CFD model; so experimental work is also still critical for continued success.

TABLE I. TEST HISTORY FOR VARIOUS IMPELLERS AND DIFFUSER CLASSES

Impeller Type	Testing per Diffuser Class and Type (y - yes; n - no; n/a - not applicable)												Grooved Covers	
	Vnls-f	Vnls-r	Vnls-b	Vnls-pa	Ch-t	Ch-a	Ch-d	Con	LSA	HSA	Tnd	Flat	Vnls	Vaned
Ns = 110, pr = 3.5	y	y	y	n	y	n	y	n	y	n	y	y	y	planned
Ns = 85, pr = 4.5	y	n	n	n	y	n	n	y/n	y	n	n/a	n	n	n
Ns = 55, pr = 1.8	y	n	n	n	n/a	n/a	n/a	n/a	y	n/a	n/a	n	n	n

Vnls-f	= front pinch Vaneless	Ch-t	= tangential divergence	LSA	= Low Solidity Airfoil
Vnls-r	= rear pinch Vaneless	Ch-a	= axial divergence	HAS	= High Solidity Airfoil
Vnls-b	= both sides pinched	Ch-d	= double divergence	TND	= Tandem Airfoils
Vnls-pa	= partial height vanes	Con	= Circular cross section	FLAT	= Flat Plate LSA equivalent

Range extension and efficiency remain the most central goals of the consortium, and to that effect, all improvements to the diffuser are valuable. Many sponsors' questions point to the need to use all three prior (1990s) consortium stages, and it is likely that this can be done now. Additionally, we have clearly seen that a deeper look MUST be taken into the complex interaction of the diffuser and the impeller; so the L2F (Laser-2-Focus for velocity and turbulence) measurements must now be pursued. This is proposed to be done for a vaneless un-grooved and grooved cover and also for a vaned set. At the same time, continued evaluation of the static pressure field, both steady and dynamic, must be continued, as significant distortion and coupling effects have been found. It is still a goal of this work to achieve 80% diffuser recovery; lessons learned from Phase VI and the flow control achieved with grooved slots are vital steps towards that goal.

Advanced diffuser design will likely exploit opportunities through controlled close coupling of the impeller and the diffuser, with resulting high stresses and some propensity for breaking. This problem can be greatly mitigated (no vanes have broken in the past six phases of the consortium). Thorough stress analysis and SAFE diagram evaluations will be part of the project and taught as part of this investigation. It has been shown to be important to understand and model the effects of close coupling and impeller/diffuser interaction to achieve advanced design goals.

Even when excellent diffusion is achieved, the work is not over! Clients have asked that we continue on to the continuous crossover, as well as volutes and simple bent diffuser systems. CFD and FEA validation work will also continue to be part of this consortium series.

We will periodically hold seminars to thoroughly teach the results obtained.

3.0 SPONSORSHIP

Diffuser Consortium Phase VI was initiated on June 15, 2013. Table II presents the participation list on April 15, 2014.

TABLE II. PHASE VI DIFFUSER CONSORTIUM SPONSORS, April 15, 2014

Concepts NREC Advanced Diffuser Consortium Phase VI Sponsors *		Phase Sponsorship								
Sponsoring Company	**Sponsorship**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**Total**
Cameron Compression Systems	Divisional	1	1	1	1	1	1			6
Dresser-Rand Company	Divisional	1	1	1	1	1	1			6
GE Aviation - Lynn Fan & Compressors	Enterprise License	**	**	**	**	**	**			0
GE Global Research	Enterprise License	**	**	**	**	**	**			0
GE Oil & Gas (AC Compressor)	Enterprise License	1	1	1	1	1	1			6
GE Oil & Gas (Nuovo Pignone)	Enterprise License	1	1	1	1	1	1			6
GE Transportation Systems	Enterprise License	1	1	1	1	1	1			6
Hangzhou Hangyang Turbomachinery	Divisional	1	1	1	1	1	1			6
Honeywell Transporation Systems - Turbo Technology	Divisional	1	1	1	1	1	1			6
Hyundai Heavy Industries Co., Ltd.	Divisional	1	1	1	1	1	1			6
IHI Corporation - Yokohama	Divisional	1	1	1	1	1	1			6
Ingersoll Rand Italiana S.p.A	Divisional	1	1	1	1	1	1			6
IR Climate Solutions (Trane)	Divisional	1	1	1	1	1	1			6
LG Electronics	Divisional	1	1	1	1	1	1			6
Rolls Royce Energy Systems (Cooper)	Divisional	1	1	1	1	1	1			6
Samsung Techwin America	Divisional	1	1	1	1	1	1			6
Shenyang Blower	Divisional	1	1	1	1	1	1			6
Siemens Oil & Gas (KK&K)	Divisional	1	1	1	1	1	1			6
Solar Turbines, Inc.	Divisional	1	1	1	1	1	1			6
Sulzer Pumps Ltd - Winterthur	Divisional	1	1	1	1	1	1			6
	Total	**18**	**18**	**18**	**18**	**18**	**18**			

***Phase VI first announced 12/13/12**

****Participating under Enterprise License**

Past consortium experience (Table III) points to increased participation as work progresses. We hope to conduct Phase VII work with an average of about 30 sponsors, potentially more.

TABLE III. CONSORTIUM SPONSORS OF THE 1990s

Concepts NREC Advanced Diffuser Consortium Phase I-V Prior Sponsors		Phase Sponsorship					
Sponsoring Company	**Sponsorship**	**I**	**II**	**III**	**IV**	**V**	**Total**
ABB Turbo Systems AG	Divisional	1	1				2
Atlas Copco Comptec, Inc.	Divisional	1	1	1	1		4
Atlas Copco Energas GmbH	Divisional	1	1	1	1		4
Babcock-Borsig AG	Divisional	1	1	1	1		4
Bharat Pumps and Compressors, Ltd.	Divisional	1					1
Cameron Compression (Cooper)	Divisional	1	1	1	1		4
Cummins Turbo Technology (Holsett)	Divisional	1	1	1	1	1	5
DAIKIN McQUAY Applied Dev't Center (McQuay)	Divisional	1	1	1	1	1	5
Dresser-Rand Company	Divisional	1	1	1	1	1	5
Elrox Engineering (PTY) Ltd.	Divisional	1					1
GE Oil & Gas (AC Compressor)	Divisional	1	1	1	1		4
GE Oil & Gas (Nuovo Pignone)	Divisional	1	1	1	1		4
GE Transportation Systems	Divisional	1	1	1	1		4
Hitachi Limited	Divisional	1					1
Honeywell Aeropsace (Allied Signal)	Divisional	1	1	1	1		4
Honeywell Aerospace (Textron Lycoming)	Divisional	1					1
Honeywell Automotive & Transportation (Allied Signal)	Divisional	1	1	1	1	1	5
IHI Corporation	Divisional	1	1	1	1	1	5
IMO Pump (DeLaval)	Divisional	1	1	1			3
IR Centac / Ingersoll Rand Italiana S.p.A	Divisional	1	1	1	1	1	5
IR Climate Solutions (Trane)	Divisional	1	1	1	1	1	5
JCI - Building Efficiency (York)	Divisional	1	1	1	1		4
Kobe Steel, Ltd.	Divisional	1	1	1	1	1	5
Nissan Motor Co., Ltd.	Divisional	1	1				2
Praxair Inc (Linde Division)	Divisional	1	1	1	1	1	5
Rolls Royce Energy Systems (Allison)	Divisional	1	1	1	1	1	5
Rolls Royce Energy Systems (Cooper)	Divisional	1	1	1	1	1	5
Solar Turbines, Inc.	Divisional	1	1	1	1	1	5
Sulzer Pumps Ltd (Escher Wyss)	Divisional	1	1	1	1		4
Teledyne Turbine Engines	Divisional	1	1				2
Thomassen Compression Systems bv	Divisional	1	1	1	1		4
UTC - Aerospace Systems (Sundstrand)	Divisional	1	1	1	1	1	5
Williams International	Divisional	1	1				2
	Total	**33**	**29**	**25**	**24**	**13**	

4.0 STATEMENT OF WORK

4.1. Phase VI (Near completion; done on June 12, 2015)

Task 1 – Project planning and control **DONE**

- Establish technical contacts with consortium sponsors
- Query sponsors to determine key interests for work via ballot

Task 2 – Full review of all past consortium test data, both pump and compressor, and examination of trends **DONE**

- Identify areas of further interest or uncertainty

- Adapt test plan to exploit any favorable interactions not capitalized on in previous consortia efforts
- Establish best sets for future modeling
- Establish strong areas for further testing
- Issue report

Task 3 – Build best models in CFD and FEA for new tests and to baseline with best prior tests **DONE**

- Aerodynamic verification of test configurations to guide test plan
- Structural verification of aerodynamic components to ensure mechanical reliability of test components
- Outline methods for aero and structural analysis of both impeller and diffuser

Task 4 – Test select impeller(s) using two vaneless diffusers, best LSA ***BEING COMPLETED**

- Select conical, tandem, and advanced generation diffuser based on all prior tests
- Further explore and characterize previously tested diffuser configurations
- Investigate potential for enhanced diffuser performance with advanced generation diffuser design

Task 5 – Extend testing with advanced time-accurate pressure **DONE**

- L2F measurements **Not Funded**

Tasks 6, 7 **Not Funded**

Task 8 – Examine limitations to current turbulence models ***BEING COMPLETED**

Task 9 – Reporting***BEING COMPLETED**

- Summary of test data and procedures, key findings, and areas for further investigation in later phases
- Issue licenses for new IP

4.2. Phase VII (Proposed: subject to sponsors' review, comments, and sponsorship)

Task 1 – Project planning and control;

- Establish technical contacts with consortium sponsors
- Query sponsors to determine key interests for work via ballot

Task 2 – Broad base with 3 impellers & vaneless, LSA/flat, channel/conical diffusers

- Continue High Ns (110) stage (pr = 3.5) for limited tests to complete matrix
- Pursue pr = 4.5, Ns = 85 stage with channel, conical and LSA diffusers
- Pursue pr = 1.8, Ns = 55 stage with vaneless, LSA and Flat plate diffusers

Task 3 – Design and develop best hybrid diffusers with best features of several tested diffusers

Task 4 – Flow-wise grooved covers

- Prepare best grooved cover (range and efficiency improvement) for two new stages

Task 5 – Pursue range more extension using multiple cover treatments in addition to the flow-wise grooved cover

Task 6 – Study detailed clearance and passage plus grooved flow at impeller exit and diffuser inlet with L2F with a *vaneless diffuser*

- Conduct L2F measurements as stated for a stage on largest consortium rig, ca. 125 mm diameter
- Evaluate data and test modeling of same with CFD

Task 7 – Study detailed clearance and passage plus grooved flow at impeller exit and diffuser inlet with L2F with a *vaned diffuser*

- Conduct L2F measurements as stated for a stage on largest consortium rig, ca. 125 mm diameter

- Evaluate data and test modeling of same with CFD

Task 8 – Time accurate CFD
- Assess practicality of existing codes to resolve clearance and grooved flow
- Assess means of extending codes
- Pursue rational extensions of existing codes to deal with two frames of reference

Task 9 – Add a symmetric or an overhung volute designed in part by MDO to give best area and radius distributions and tongue shape; test in vaneless mode; use laser sintering to produce volute

Task 10 – Update TEIS models for impeller
- Revise correlations and update design database
- Explore impeller and diffuser coupling effect on TEIS parameters for enhanced modeling capabilities

Task 11 – Update TEIS models for diffuser
- Study behavior in new test data and compare to existing correlations
- Add test data to design database and validate models
- Improve numerical modeling capabilities for wider range of stationary vaned diffusing elements

Task 12 – Reporting
- Summary of test data and procedures, key findings, and areas for further investigation in later phases
- Issue IP licenses

Deliverables: Periodic reports (approximately every eight – twelve weeks), a detailed formal (bound) report, and formal presentations will be given. A sponsors' meeting will be held in Wilder, VT, to promote thorough communication. Patent licenses will be issued.

4.3. Phase VIII Focus

- Breadth of application; confirm trends
- Resolve remaining paradoxes, as possible
- Add additional volutes and impeller designs as needed
- Testing with additional diffusers – increased novelty/risk on diffuser types (test in water and/or air)
- Possible PIV studies
- Possible LES calculations
- Licenses granted; new patents

4.4. Supplementary Data

A *tentative* schedule for release of supplementary data, so far as it is not proprietary to third parties, is as follows:

- 2014 – add Stability Consortium - **DONE**
- 2015 – add Return Channel I - **N/A**
- 2016 – add Return Channel II – **N/A**
- 2017 – add NREC large stages I
- 2018 – add NREC large stages II
- 2019 – add NREC range extension
- Other –SBIRs; other Government

This release schedule is not binding and will be adapted to best support the flow of work in the project. Participation in early phases of work does not entitle access to these data unless sponsorship is current in all phases of work to date.

5.0 TIMING, COST, AND SCHEDULE

5.1. Continuing Sponsorship, Current Sponsors

Continuation is simple at $15,000 per year, same as the past two years. No new regulations are applied.

5.2. Conventional Sponsorship, New Sponsors UNTIL JUNE 15, 2015

All new sponsors can find their situation in one of the following charts:

First Time Sponsor					
Prices	Phase I - V	Phase VI, Yr 1	Phase VI, Yr 2	Phase VII, Yr 1	Totals
Base Price-June 16	$65,000	30,000	30,000	15,000	$140,000
Credits until June 15th, APS*	32,500	15,000	15,000	0	62,500
Division Price**	$32,500	$15,000	$15,000	$15,000	
Grand Total					$77,500
* Current APS members receive a 50% discount on Phase I-V work at present * Current APS member divisions may receive a roll back of Phase VI late fees ** This pricing applies to any individual division that is current in APS					

Prior Sponsor, Phases I - V (Six eligible company divisions)					
Prices	Phase I - V	Phase VI, Yr 1	Phase VI, Yr 2	Phase VII, Yr 1	Totals
Base Price-June 16	$0	30,000	30,000	15,000	$75,000
Credits until June 15th, APS*	0	15,000	15,000	0	30,000
Division Price**	$0	$15,000	$15,000	$15,000	
Grand Total					$45,000

Prior Sponsor, Phases I - IV (Five eligible company divisions)					
Prices	Phase I - V	Phase VI, Yr 1	Phase VI, Yr 2	Phase VII, Yr 1	Totals
Base Price-June 16	$20,000	30,000	30,000	15,000	$95,000
Credits until June 15th, APS*	10,000	15,000	15,000	0	40,000
Division Price**	$10,000	$15,000	$15,000	$15,000	
Grand Total					$55,000

Prior Sponsor, Phases I - II (Four eligible company divisions)					
Prices	Phase I - V	Phase VI, Yr 1	Phase VI, Yr 2	Phase VII, Yr 1	Totals
Base Price-June 16	$40,000	30,000	30,000	15,000	$115,000
Credits until June 15th, APS*	20,000	15,000	15,000	0	50,000
Division Price**	$20,000	$15,000	$15,000	$15,000	
Grand Total					$65,000

Prior Sponsor, Phase I (Four eligible company divisions)					
Prices	Phase I - V	Phase VI, Yr 1	Phase VI, Yr 2	Phase VII, Yr 1	Totals
Base Price-June 16	$55,000	30,000	30,000	15,000	$130,000
Credits until June 15th, APS*	27,500	15,000	15,000	0	57,500
Division Price**	$27,500	$15,000	$15,000	$15,000	
Grand Total					$72,500

If you are not a current APS (Agile Product Support) client, you can become one very inexpensively. If you are a CN software user but are not current on support, simply update your support for any part of or your entire CN design suite. If you are not a CN software user, you will want to start with a seat of COMPAL® or PUMPAL®[1], which has an entry price of $16,000. This is clearly attractive economics.

Phase VII work will be initiated on June 15, 2015, with the base fee of $15,000 per year for two years ($30,000 total). Companies who sponsored Phases I – VI (on a per division basis) join this Consortium Phase VII with only the annual fee.

Additional sponsors are welcome at any time (see charts above) and will be required to become current with the six prior phases of the consortium plus current phases. The catch-up fees are as shown above. Note: annual fees increase by 50% after a work phase *starts* and by 100% after the phase of work *ends*.

All patent rights established during the course of this project will be available to Phase VII consortium members (as of June 16, 2015, to June 15, 2017) with a worldwide, royalty-free, non-exclusive license. Any organization joining upon the completion of this project will be required to obtain patent rights through a separate license agreement at an additional cost. A patent has already been issued for Phase VI work, and will be included up to June 15th, 2015. After that date for the rest of 2015, the patent can be licensed to *new consortium members* for $40,000 additional.

The prices that apply **after** June 15th are shown in blue in the charts above; but please add the $40,000 for the patent rights as well. Hence, the full post-June 15th prices range from $22,500 to $187,500 at the present time, see table below: The discounted prices are only $15,000 to $77,500 for the first 6.5 consortium phases.

[1] COMPAL and PUMPAL are registered trademarks of Concepts ETI, Inc.

Cost Comparison After June 15th and Before				
Past Sponsorships	Fees	IP License	Full benefit sponsor after June 15th	Before June 15th APS member
None	$147,500	$40,000	$187,500	$77,500
I	$137,500	$40,000	$177,500	$72,500
I & II	$122,500	$40,000	$162,500	$65,000
I - III	$112,500	$40,000	$152,500	$60,000
I - IV	$102,500	$40,000	$142,500	$55,000
I - V	$82,500	$40,000	$122,500	$45,000
I -VI	$22,500	$0	$22,500	$15,000

Customers do, of course, complain about the cost of the catch up fees. In fairness, however, we must point out that all present sponsors have paid these fees and have profited from the work; new sponsors likewise profit from the work and need to carry their fair share of the costs. It should be remarked that, of the current 18 sponsors, 6 were new entries and quickly paid up all past fees; additionally, 6 more sponsors paid up their last 1 or 2 years for catch-up (and 6 were full sponsorship roll overs from the 1990's).

It is the intent of CN to phase out **all** *discounts for this Diffuser Consortium work after June 15, 2015. Patent license fees will increase annually for new sponsors. A summary of this offering is given in the table above. It may be seen that current prices are less than ½ of those starting on June 16th.*

Special pricing is available on an enterprise-wide basis; please contact Mel Mittnick (781-937-4631, mmittnick@conceptsnrec.com) or Jim McNamara (802-280-6126, jmcnamara@conceptsnrec.com) at *CN* for assistance. Businesses located in Asia often use a fiscal year different from the calendar year; please contact *CN* for assistance in setting dates.

5.3. Planning, Communication, and Schedule

The work tasks will be executed in the order presented above, unless clearly redirected by vote of the consortium sponsors. With the registration application, a brief questionnaire/ballot is included. This questionnaire provides some additional and formal feedback from the sponsors; questions concerning the preferred priority rating of the tasks are offered. If a clear preference from the sponsors is established, contrary to the order of tasks presented above, an alternative strategy will be proposed and reviewed with the sponsors.

The time required to carry out the proposed work is twenty-four (24) months. Tasks 1, 2, and 9 require 18 participants (or 9 sponsors over two years) and are the central focus of the first year of this two-year program; Task 3 will require an additional 4 participants; Tasks 4 and 5 will require an additional 4 and 5 sponsors, respectively; Task 6 requires 3 sponsors; Task 7 will require an additional 4 participants. Tasks 8 and 9 require 3 sponsors each and Task 10 is built into the other items. Two copies of the final report will be provided to each group; additional copies may be purchased at a price of $85 each, plus shipping and handling. Any original sponsor needing additional copies of the earlier work may request copies at the same price.

Based on past experience, *CN* anticipates reaching a level of approximately thirty (30) sponsors in 2015, with more to be added later. This level will allow all tasks to be accomplished. This anticipation is based upon the historical strength of all diffuser-related investigations under the *CN* consortia activities, the strengths of the present proposal, the patent-protected base technology, the recovering economy, and the wide need in industrial circles to have well-developed design options based on advanced technology.

The results of this investigation will be proprietary. The proprietary restrictions shall be imposed on the general diffuser data for seven years commencing June 16, 2015. After June 15, 2022, unrestricted use may be made of these data. *CN* will also utilize the data, with strict controls, to encourage CFD houses to enhance modeling accuracy. *CN* reserves the right to publish limited sections of the work to bring in more sponsors, and hence, extend the work. Each sponsoring organization agrees that it will maintain the same proprietary protection for the information resulting from this study as it would afford to similar proprietary data taken within their own organization.

Additional past related research consortia are available to augment, in future years, the work proposed above. Throughout subsequent years, additional diffusion data and design information will be released to all current sponsors. This will include massive amounts of data on return channels, stage stability, flow control/treatment, volutes, and so forth. The information collected in some 20 past research consortia is truly massive and will be exploited over the six-year term of the complete project. Additionally, three (3) theses have been written on related modeling, and these are an integral part of the program activities.

This is the largest technology program ever launched for radial turbomachinery, and the largest ever technology base for compressor diffusers has been compiled.

6.0 CLOSURE

CN is firmly committed to identifying and developing advanced turbomachinery components and systems. This project will give the basis for further performance gains, particularly with respect to range and efficiency, and with respect to application over diverse regimes of operation. An extensive database of numerous geometric configurations has been established and will be extended. The role of CFD is vital and will be extended through the present work. The present investigative process has led, and shall continue to lead, to the most extensively conducted tests ever undertaken on diffusing systems concerning centrifugal compressors and pumps. These results provide a coherent database upon which designers can establish future designs and minimize their efforts to optimize designs for new industrial stages. The use of refined CFD techniques holds great promise for future design optimization. In later portions of this project, advanced CFD techniques are expected to change the method of optimizing future industrial stages.