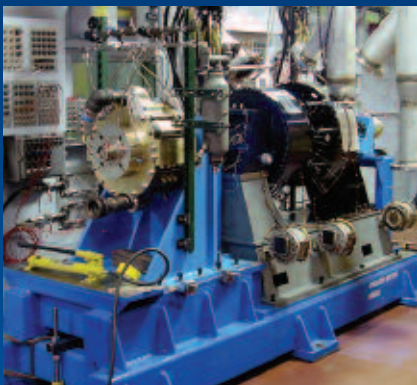
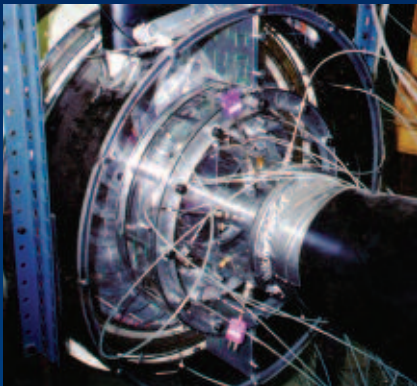


CONCEPTS NREC

PERFORMANCE TESTING

**for Development and Validation of
Pumps, Compressors, Turbines, and Other
Turbomachinery Components**



- Component, Assembly, and System Testing
- Design, Performance, and Software Validation
- Standard, Modified, and Custom Rigs

A Legacy of Breakthrough Methods and Turbomachinery Advances

In a quest to engineer and manufacture more robust turbomachinery with improved performance, designers are moving into new operating scenarios that require a better understanding of the fluid-dynamic phenomena which impact performance. To lessen or eliminate risk within these new design envelopes, it is essential to both calibrate design tools which are being used outside of their calibration range, and simultaneously test the turbomachinery operating in these new envelopes.

That is why both sophisticated testing facilities and extensive testing experience are needed to develop many of today's high-performance turbomachinery components and systems. The expertise gained by

Concepts NREC in planning and conducting literally hundreds of turbomachinery tests has developed into a core competency that now supports our customers' turbomachinery design efforts — and also helps validate our own proprietary design tools.

Concepts NREC is the world's leading independent, full-service turbomachinery design and development organization and has conducted more turbomachinery testing than any other group. For a half century, we have provided manufacturers, end users, government agencies, and the engineering community with technology tools, engineering services, system designs, testing services, and components that have helped them develop, produce, and utilize the world's most advanced turbomachinery products.

Concepts NREC can plan the most optimum testing program to achieve a customer's objectives, provide standard or custom test rigs for use in our test cells or at the customer's specified site, and deliver these and other testing services on a timely and cost-effective basis. Please contact Concepts NREC corporate headquarters or visit our website for more information.



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Performance Testing and Assurance for Advanced Turbomachinery Designs

Sophisticated facilities and extensive experience provide accurate test data

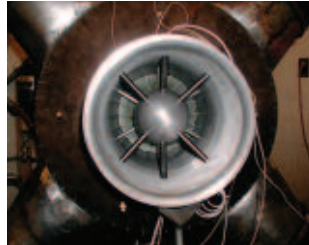
Concepts NREC is an industry leader in turbomachinery test-rig design, fabrication, and operation, with state-of-the-art testing facilities equipped to validate the operating specifications and design objectives of today's advanced turbomachinery pumps, compressors, and turbines. As an independent testing service with fifty years of turbomachinery experience, Concepts NREC routinely and accurately provides proof of design integrity, as well as development testing, for the needs of equipment manufacturers, end users, and government agencies.



The NOTAR helicopter fan underwent testing in a custom test rig.

Concepts NREC test rigs and methods provide the data needed to verify the aerodynamic performance, structural behavior, or the dynamic behavior of individual components or complete systems, as well as to identify and correct problems. Testing is typically conducted to:

- Validate designs
- Validate software design/analysis tools (meanline to CFD)
- Generate failure analyses
- Improve structural integrity
- Simplify designs
- Improve performance
- Optimize fuel efficiency
- Decrease noise
- Reduce emissions
- Lower operational costs
- Rerate an application



An axial compressor stage is tested in a standard Concepts NREC test rig.

The extensive testing facilities, knowledge, and experience developed by Concepts NREC can be adapted to a wide variety of requirements for evaluating both scale-model prototypes and full-dimension turbomachinery components as well as complete machines. This unique synergy of capabilities includes:

- Specialized test cells to match specific speed, power, and instrumentation requirements
- Experienced design/test engineers to structure an efficient and cost-effective test program
- Proprietary software to maximize the accuracy and the value of the data acquired
- Unique magnetic-bearing test rigs that can make dynamic force measurements
- Access to exceptional applied expertise in data analysis for cost-effective design modifications



This axial compressor stage is instrumented with strain gauges and telemetry.

Concepts NREC routinely tests a great variety of turbomachinery elements that include axial and radial compressors, turbines, and pumps. Several standard test rigs are always in place to quickly accommodate typical turbomachinery components and testing objectives. These rigs offer exceptional flexibility, reliability, and quality data. For unique testing requirements, Concepts NREC can design, build, and instrument a custom rig to be used wherever needed.



An industrial pump stage is prepared for performance and cavitation testing.

Test equipment and capabilities cover a wide range of equipment sizes, flow rates, and pressure levels for :

- Compressors
- Fans
- Blowers
- Pumps
- Turbochargers
- Turbopumps
- Air-cycle machines
- Industrial gas turbines
- Aerospace gas turbines
- Fuel-cell turbomachinery
- Others per request



This custom test rig is for the development of advanced brush seals.

In addition to testing complete machines and major turbomachinery subsystems, testing is also available for individual components that include:

- Impellers
- Inducers
- Inlets
- Exhausts
- Diffusers
- Ducts
- Return channels
- Deswirl vanes
- Combustors
- Heat exchangers
- Instrumentation
- Seals
- Bearings



Gas-turbine drives are available for compressor testing and development.

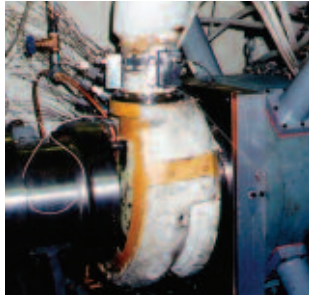
Extensive facilities and advanced tools provide cost-effective data

Concepts NREC can efficiently plan and accurately conduct most turbomachinery testing in-house using available supporting hardware and methods that include a specialized facility for testing pumps. Having the total resources and experience to meet a client's exact requirements can significantly reduce testing costs and completion times. And costs plus delivery schedules for custom designed and fabricated test rigs are also reduced by using standard subassembly mechanisms.

Concepts NREC can provide standard, modified, or custom test-rig solutions to match specific testing requirements and other project constraints. Any rig can be employed in a Concepts NREC test cell or installed at a customer's specified site. Offsite rigs rely on the customer's engineering professionals to generate and interpret test data and allow close control over proprietary technologies.



This custom gas-turbine test rig is installed in the client's facility.



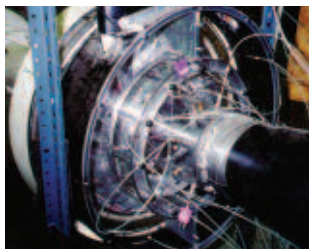
This pump test rig uses components from the SSME liquid hydrogen fuel pump.



Standard rigs. Individual elements or complete stages can be tested in existing, standard rigs.



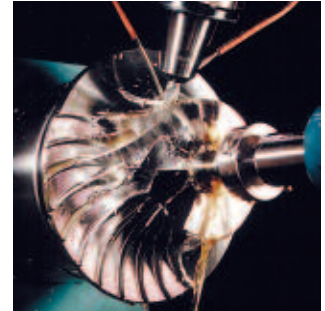
Modified rigs. Modifications can be made to a standard rig for unique applications or testing objectives.



Custom rigs. For unique hardware or test requirements, custom rigs can be designed and tested.

Several aerodynamic and hydrodynamic test cells at both Concepts NREC facilities are available to accommodate a large range of speed and power requirements for the operation and testing of turbomachinery systems.

- Existing standard rigs accommodate components from 2 inches in diameter up to over 24 inches in diameter.
- High-power drives up to 3,000 hp provide high-speed/higher power testing.
- Overspeed spin pits run up to 200,000 rpm to assure mechanical integrity.
- Flow rates over 80 lbm/s have been tested.
- Pump tests can be performed over a wide range of inlet pressures.

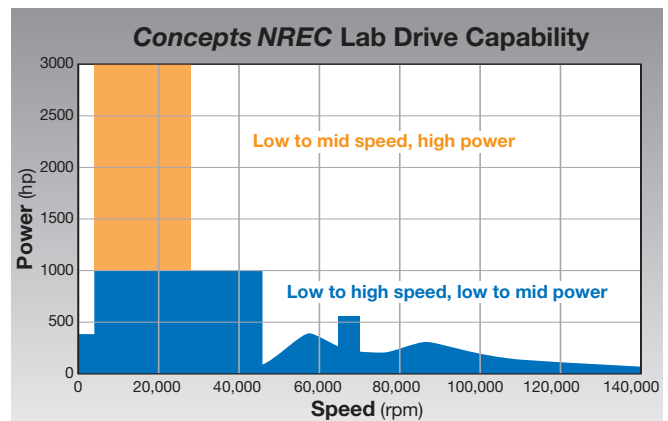


In-house 5-axis machining is used to manufacture test hardware.

Test rigs and cells also contain complete instrumentation from standard pneumatic and thermal probes to more sophisticated hot-film anemometers, laser velocimeters, high-frequency pressure transducers, strain-gauge telemetry, and proximity probes, plus a data-acquisition system that accurately reports test results. In addition to dynamic testing, Concepts NREC also operates a fully-equipped prototype machine shop with five-axis machining centers, conducts mechanical inspections, and performs modal testing and strain-gauge testing.



Turbine-driven spin pits are available for proof testing.



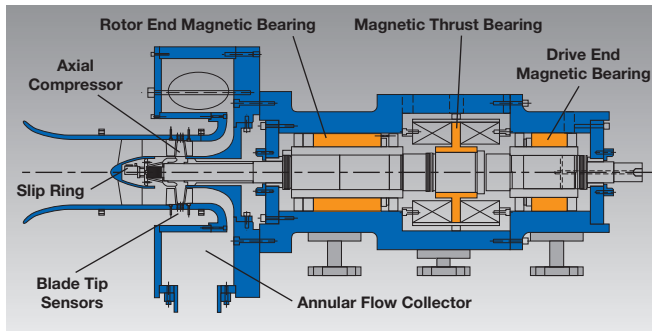
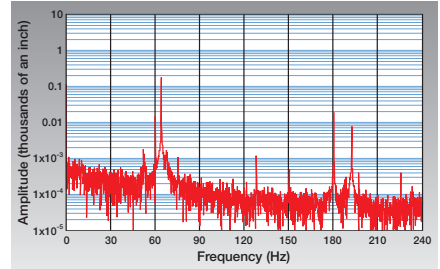
A wide range of drive capability is available for various test needs.

Magnetic bearing rigs accurately measure unsteady force coefficients for improved design

To better facilitate new insights and understanding of fluid-induced and unsteady rotordynamic forces, Concepts NREC has developed several world-class dynamic testing facilities that use magnetic

bearings along with a dual-ellipse-orbit measurement technique. These rigs can determine the dynamic forces on rotating impellers, bearings, seals, couplings, and other components, and provide

designers with the information necessary to develop the next generation of advanced pumps, compressors, and turbines for various industrial, aerospace, and commercial applications.



The unique capabilities of magnetic bearing-based test rigs are available for pump, compressor, and seal testing.

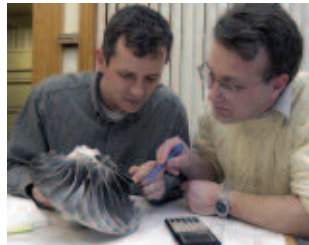
In addition to supporting the test element, the magnetic bearings provide dynamic excitation of the test element by precisely controlling the position and vibration, while also measuring the fluid forces created either by movement of the component or by the operating load. A full suite

Magnetic bearing test rigs provide an extensive range of data acquisition capability.

of flow, pressure, temperature, and flow visualization techniques also provide for an accurate characterization of aerodynamic or hydrodynamic performance.

Knowledgeable and experienced test engineers provide needed results for competitive cost

Experience is a critical advantage for interpreting a client's data requirements into a test program that delivers the information desired to the level of accuracy needed while keeping in mind the best approach to minimize costs. Concepts NREC offers its customers access to an extensive staff of design, aerodynamic, and structural engineers, instrumentation specialists, and lab technicians using the most advanced tools and equipment



Concepts NREC engineering design staff is available to support rig design projects.

available. This highly knowledgeable and experienced team of experts is capable of all facets of rig design and fabrication as well as data acquisition, data analysis, and design resolution.

Experience enables engineers to correctly position sensors for measuring speed, flow rate, temperature, and pressure with maximum data relevance and quality. Instrumentation available to support data acquisition includes traditional

pneumatic and thermal probes and traverses, sophisticated hot-wire/hot-film and laser anemometers, high-frequency pressure transducers, and proximity probes.

Concepts NREC engineers are also experienced designers of data-acquisition systems that feed data directly to design codes for further data reduction and comparison to design goals. This capability enables engineers to quickly and accurately diagnose turbomachinery operating problems and

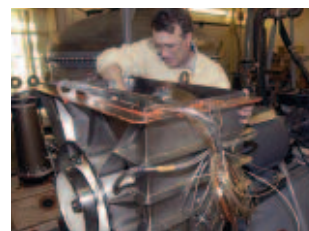


Precision manufacturing and inspection are critical for obtaining high-quality test hardware.

make effective, practical recommendations for fixes. It also aids Concepts NREC's internal research and development activities by feeding validation data to our design tools, which in turn leads to more accurate design software.



Experienced test engineers ensure successful test projects.



Specialists select and install test-rig instrumentation.

Solutions for a variety of testing requirements assure the success of each new project

The cumulative experience of developing many hundreds of rig tests demonstrates how Concepts NREC can successfully apply testing know-how

to analyze the performance, efficiency, and durability of both individual components and complete turbomachinery systems.

Components tested include:

- Impellers
- Rotors
- Inlets
- Diffusers
- Return channels
- Seals
- Deswirl vanes
- Combustors
- Open- and closed-loop systems

Compressors, Fans, and Turbines

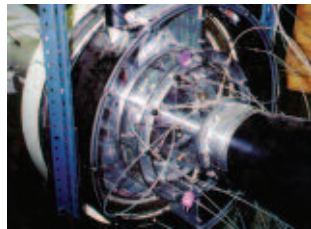
Standard test rigs including magnetic bearing rigs are available to analyze the operational performance of both single and multistage industrial, aerospace, turbocharger, and refrigeration compressors, turbines, pumps, and fans. Typical tests include:

- Overall stage performance
- Internal/interstage measurements to separate out individual component performance
- Open- and closed-loop testing
- Testing at various pressure levels and with various gases to examine Re effects
- Both steady-state and high-frequency pressure measurements (to look for rotating stall, for instance)

Industrial Compressor

Challenge

Design a custom test rig for an industry leader in energy conversion technology to study the effects of sidestream injection in a multistage industrial compressor.



Solution

Concepts NREC developed a large-scale, clear-plastic rig for flow visualization and pressure measurements. A primary air supply simulated the main flow, while a second heated air supply was provided for the sidestream injection flow. Flow rates were around 7 lbm/s. The mixing of the two streams was measured both by flow visualization and pressure measurements.

Benefits

The client was able to use the data collected in the rig to better understand the mixing of the sidestream flow and to help validate their CFD analysis. A technical paper was subsequently written describing the results.

Aerospace Gas Turbine

Challenge

Design, fabricate, instrument, assemble, and deliver a unique turnkey turbine-testing rig needed quickly by a major aerospace gas-turbine company. Among the requirements was a very tight tip clearance.

Solution

Concepts NREC developed a rig static structure and shafting/rotordynamic system to meet the unique design requirements of this rig. Concepts NREC fabricated and assembled the rig, and then performed shakedown testing to validate the rig design.

Benefits

The custom rig was delivered to the customer's facility, allowing engineers to collect critical test data and do their own data analysis on site.



Turbochargers and Fuel-Cell Blowers

Turbocharger and fuel-cell manufacturers and users often use Concepts NREC test rigs to confirm the accuracy of theoretical predictions, to measure overall performance, and to evaluate internal element performance. Typical tests include:

- Performance for compressor, blower, and turbine elements
- Flow visualization
- Strain-gauge testing
- Modal testing
- Vibration and noise testing

Automotive Turbocharger

Challenge

An automotive manufacturer needed to quickly develop and test a prototype fuel-cell blower to be used in a demonstration vehicle.



Solution

To compress the time frame and perform the tests on schedule, Concepts NREC modified an existing off-the-shelf turbocharger to accommodate the new blower design. The unit included variable turbine geometry while still using the existing bearing housing. Blower performance maps and turbine performance maps were then generated over a range of turbine vane settings to acquire the target data.

Benefits

Design, fabrication, and testing were completed in a very short time frame, and completed on schedule. By taking full advantage of Concepts NREC's expansive resources to design, fabricate, and test the fuel-cell blower completely in-house, the customer received both a working prototype and measured performance data in time to meet their deadline.

Chillers and Refrigeration Compressors

Concepts NREC offers both continuous and cycling testing of compressors and diffusers for the refrigeration industry utilizing the actual refrigerant specified for the compressor. Testing is conducted to measure, evaluate, and validate both the thermodynamic stability and efficiency of complete systems as well as to verify the performance of individual internal elements. Typical tests include:

- Cycle performance
- Stage performance
- Flow visualization
- Mechanical tests

Pumps and Turbopumps

Concepts NREC operates one of the world's most advanced pump testing facilities with comprehensive and specialized testing capabilities. Testing technologies include overall performance testing, cavitation testing, and dynamic force testing.

Magnetic bearing rigs provide dynamic force measurements and help establish dynamic coefficient matrices for pump impellers and seals. Improving suction performance with a better understanding of unsteady dynamic forces is a critical path for achieving significant increases in rotational speed which can drastically reduce pump size and cost. Typical tests include:

- Performance
- Cavitation
- Rotor dynamics
- Modal testing
- Dynamic force measurement

Air Cycle Refrigeration

Challenge

A commercial air cycle machine vendor needed testing to verify mechanical operation and aerodynamic performance of an air cycle compressor/turbine.



Solution

The air cycle units were tested in an existing test cell, using appropriate instrumentation to also measure mechanical parameters (vibration, shaft orbits, axial thrust loads) and aerodynamic parameters (component pressure and temperature ratio, and internal static pressure distributions).

Benefits

The air cycle unit was successfully tested over a range of speeds, flows, and pressure ratios at Concepts NREC test labs to provide data that showed design goals had been met.



Turbopump

Challenge

A government agency contracted with Concepts NREC to quantify impeller hydrodynamic coefficients in cavitating inducers and impellers typical for a turbopump design.

Solution

Force measurement techniques were developed using magnetic bearings to support the rotor, allowing the imposition of prescribed whirl orbits on the test impeller while simultaneously measuring hydrodynamic interaction forces. This permitted hydrodynamic coefficients of the impeller to be quantified as a function of cavitation number and whirl frequency.

Benefits

This unique measurement technique resulted in more accurate modeling of turbopump rotor-dynamics than other methods.



Industrial Pump

Challenge

An industrial pump manufacturer needed to improve the performance of a series of clear water pumps while also achieving exceptionally high-efficiency goals.

Solution

Concepts NREC supplemented the results from detailed flow predictions and CFD analysis with rig test data to optimize the pump designs and validate the CFD analysis. Overall performance data as well as impeller exit station measurements were collected to determine local spanwise velocity profiles plus separate performance of the impeller and return system.

Benefits

The manufacturer was supplied with an improved pump design which met their high-efficiency design goals. And, because testing was used to verify design iterations, the customer received actual tested performance data as opposed to mere analytical predictions.



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