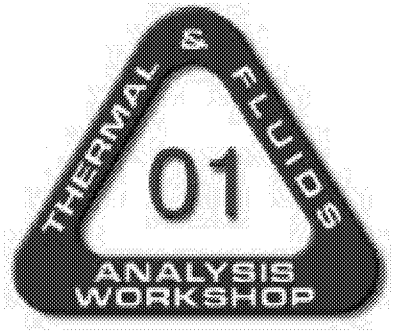
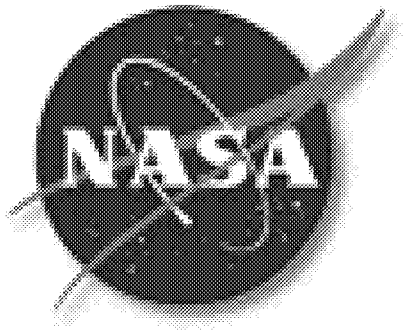




Experimental Study of Unshrouded Impeller Pump Stage Sensitivity to Tip Clearance

September 10, 2001

Robert W. Williams, Thomas Zoladz, Anne K. Storey, and Stephen E. Skelley
NASA Marshall Space Flight Center, AL 35812

Background

- A turbopump develops required head by spinning very fast
  - The faster the pump rotates, the more head is generated
- A shroud is a heavy metal casing which covers blade passages
  - Shrouds help maintain performance and control axial thrust
- As a pump spins faster, stresses due to centrifugal force increase
  - The weight of the shroud increases the stress on the blades
  - This stress limits the speed at which a pump can operate
- A pump impeller without a shroud has less centrifugal force
  - Unshrouded Impellers operate at higher speeds with lower stress
  - Higher speeds allow Unshrouded impellers to generate more head
  - Use of unshrouded impellers allows for reduction of pump stages
- Tip clearance affects performance of unshrouded impeller
  - Experimentally quantify tip clearance effects on pump performance

Unshrouded Team Members

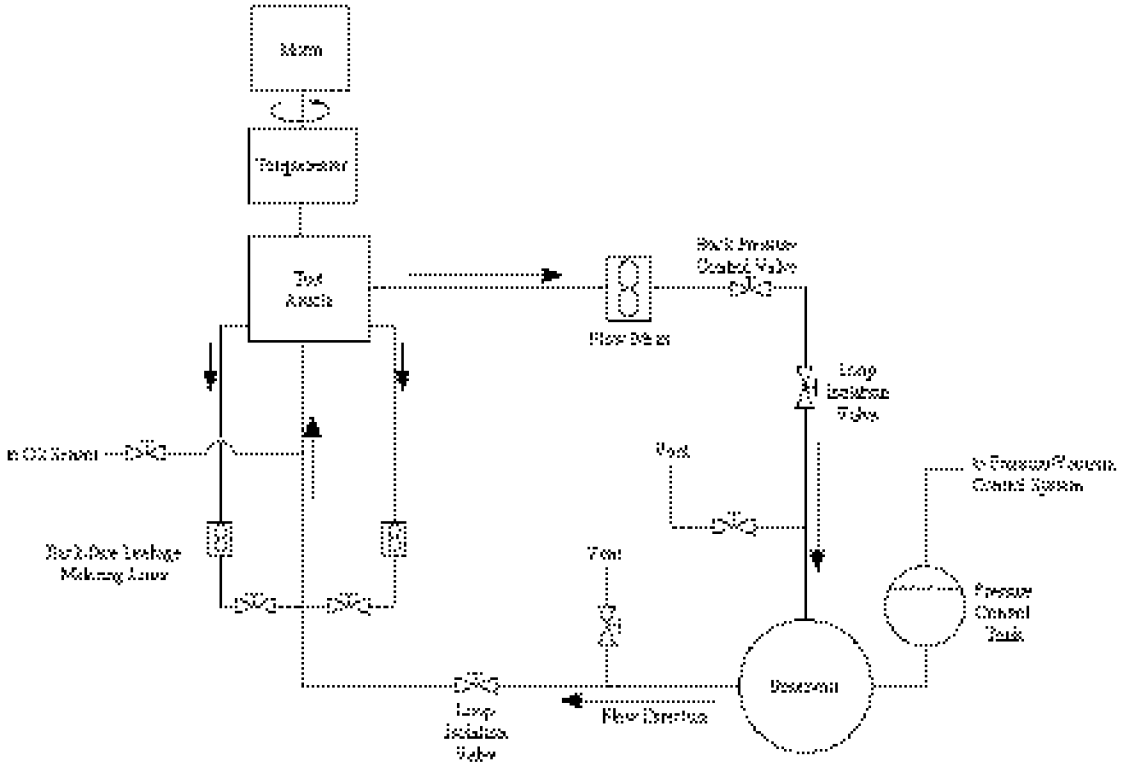
- MSFC Support
  - TD63 - Test Engineer, *Skelley*; Unsteady Data Reduction, *Zoladz*; Test Article Build Engineer, *Branick*
  - TD64 - Impeller Design, Analysis, Test Engineer, and Mgmt, *Williams*
  - TD74 - Facility Engineering and Facility Operations, *Storey & Jones*; Instrumentation and Controls, *Bush, Norman & McBride*; Calibration Wind Tunnel, *Gerry*; and Data Acquisition, *Kirkpatrick*
- Contractor Support
  - Pratt & Whitney - IGV, Baseline Impeller, and Diffuser Design, *Erler*
  - Boeing, Rocketdyne - Advanced Impeller Design, Analysis, and Tool Development, *Prueger, Chen, & Williams*
  - $A^2 I^2$ (Micro Craft Inc.) - Rig Mechanical Design and Fabrication, *Tyler*

Experiment Objectives and Approach

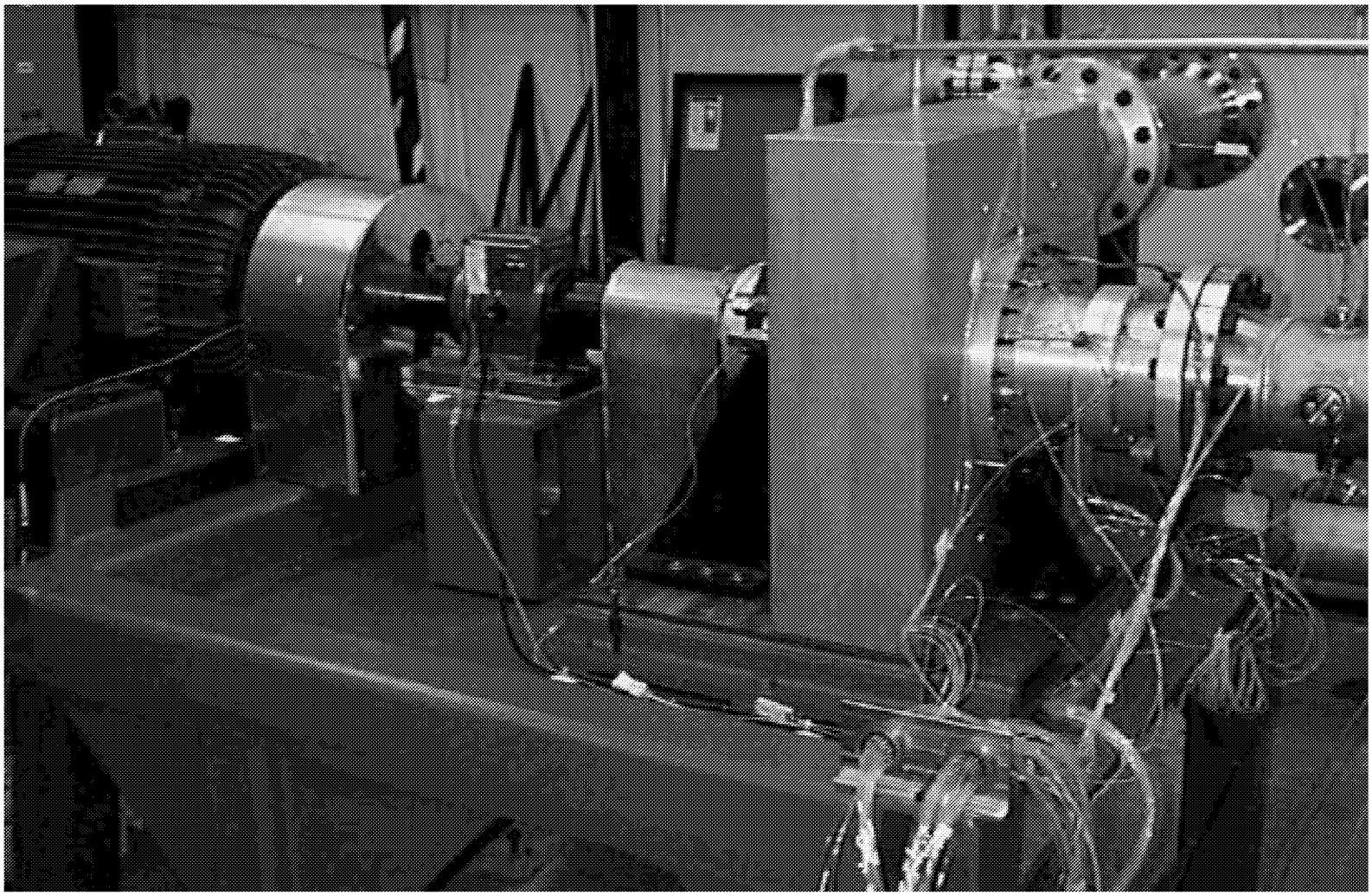
- Objective:
  - Experimentally determine unshrouded impeller performance sensitivity to tip clearance
- Approach:
  - Determine impeller efficiency at scaled operating conditions in water at MSFC's Pump Test Equipment (PTE) Facility
  - Test unshrouded impeller at three different tip clearances
  - Test each tip clearance configuration at on- and off-design conditions
  - Collect unsteady- and steady-state data in each configuration
  - Determine impeller efficiency directly using drive line torquemeter and pump inlet and exit total pressure measurements

Facility Description

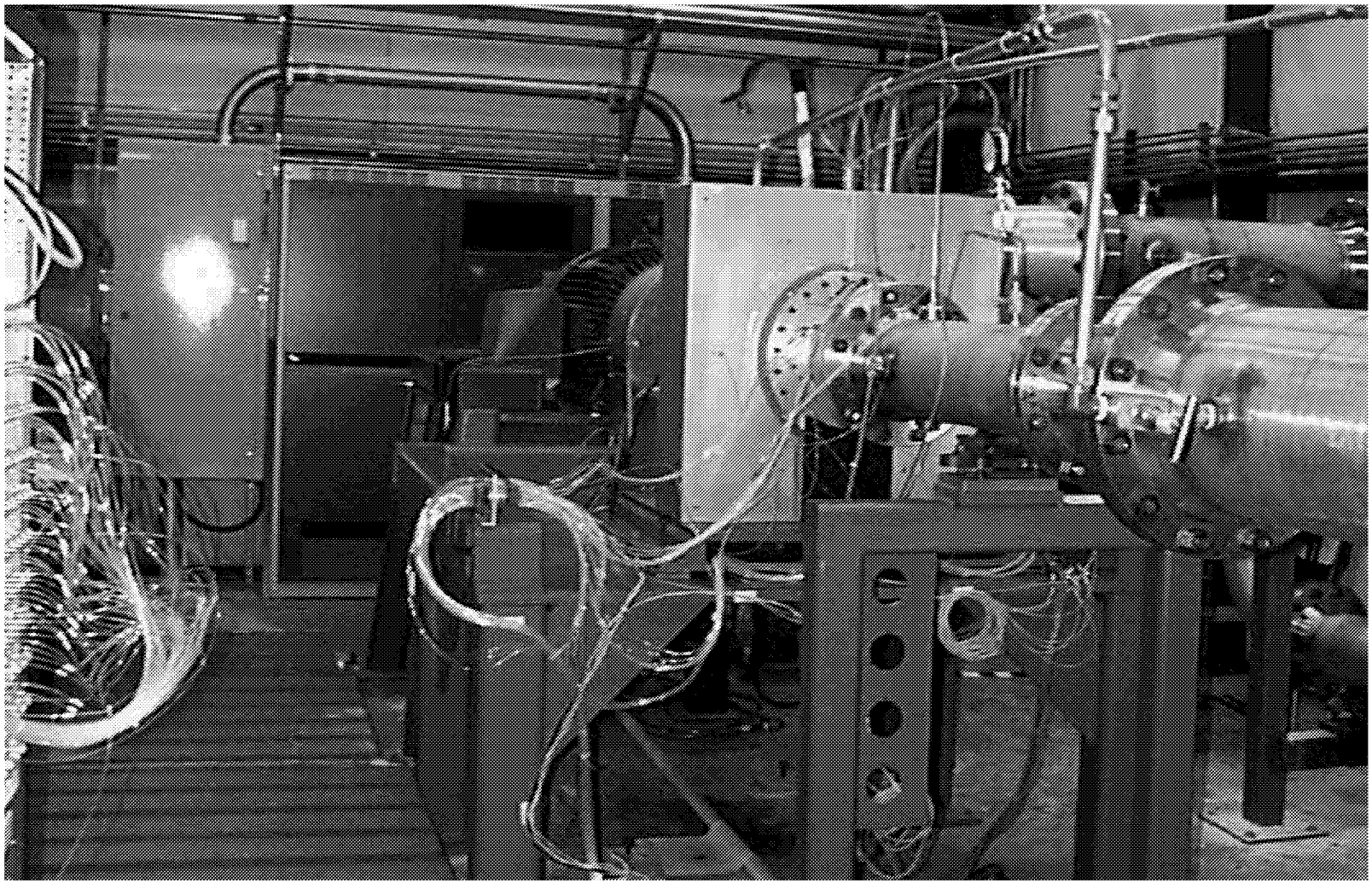
- Test was conducted at MSFC's PTE Facility
  - PTE is a closed-loop water flow facility with 10,000 gallon reservoir
  - Deaeration and pressurization systems, facility flow meter, flow control valve, torquemeter, and 350 horsepower drive motor



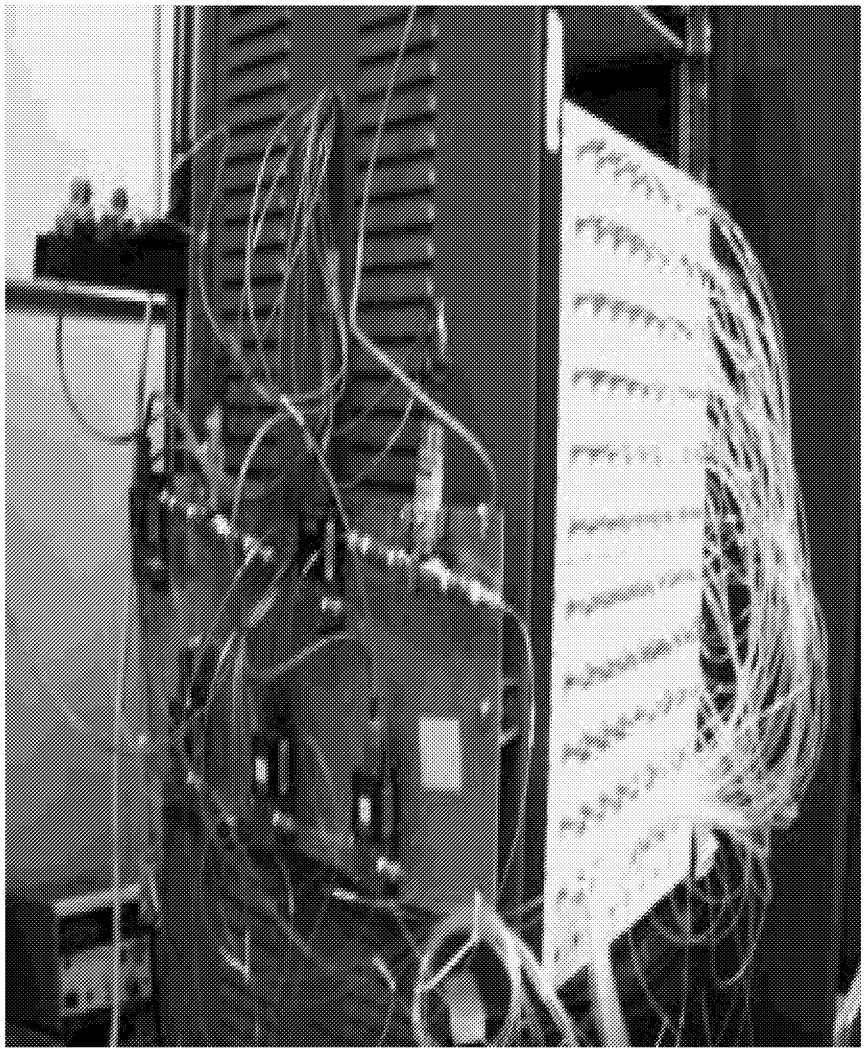
Unshrouded Impeller Technology Water Rig



PTE Test Stand and Instrumentation Rack



Instrumentation Rack



- Housing for pressure transducers, SCXI modules, and power supplies
- Transducers selected for application, accuracy, and range
  - Honeywell
  - Validyne
  - Druck
  - Sensotec

Real Time Data Display Reduction

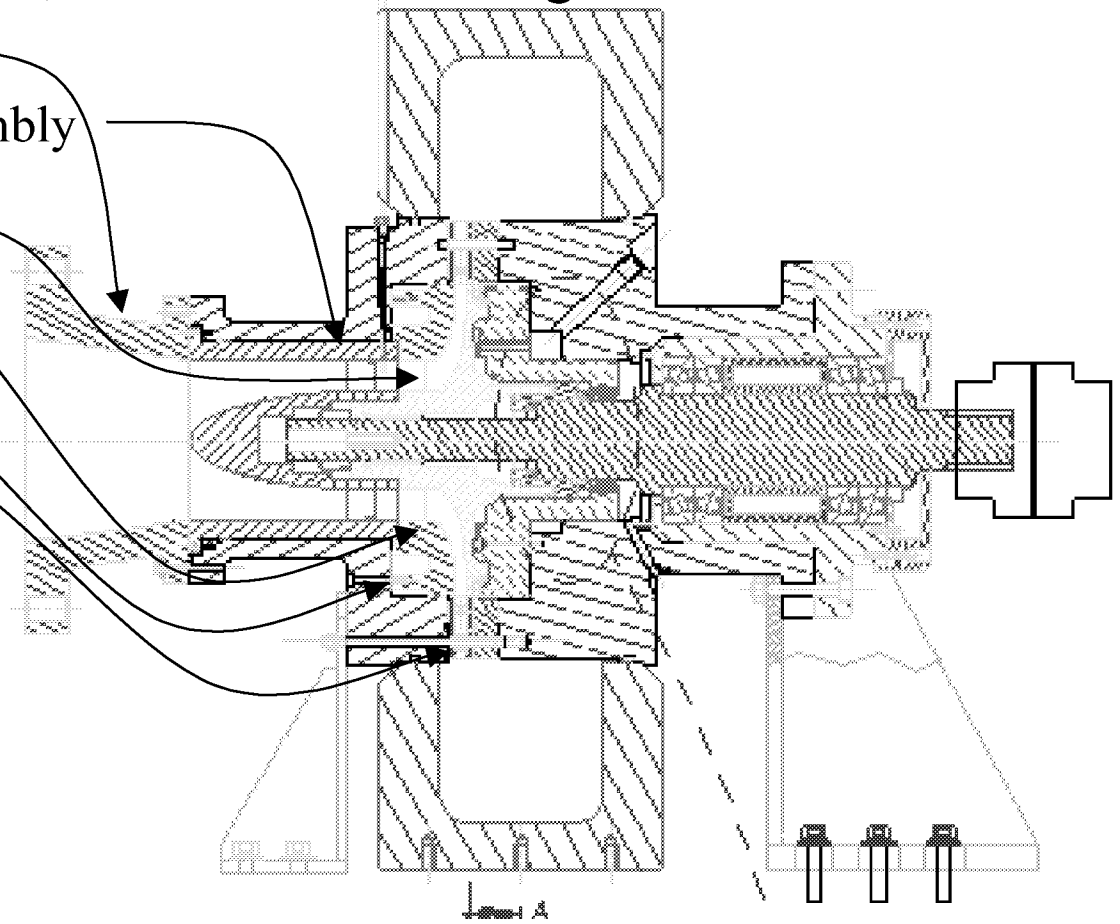
- LabVIEW measurement and display system
  - Continuously update and display the set point parameters
  - health monitoring measurements
    - Temperature
    - Leakage flow
- LabVIEW data storage system
  - Pressures
  - Flow rates
  - Temperatures
  - Speed
  - Torque
- Detailed reduction and analysis
  - Completed later by test engineer using stored data
  - Reduction performed using excel spreadsheet

PTE Facility Operation Panel

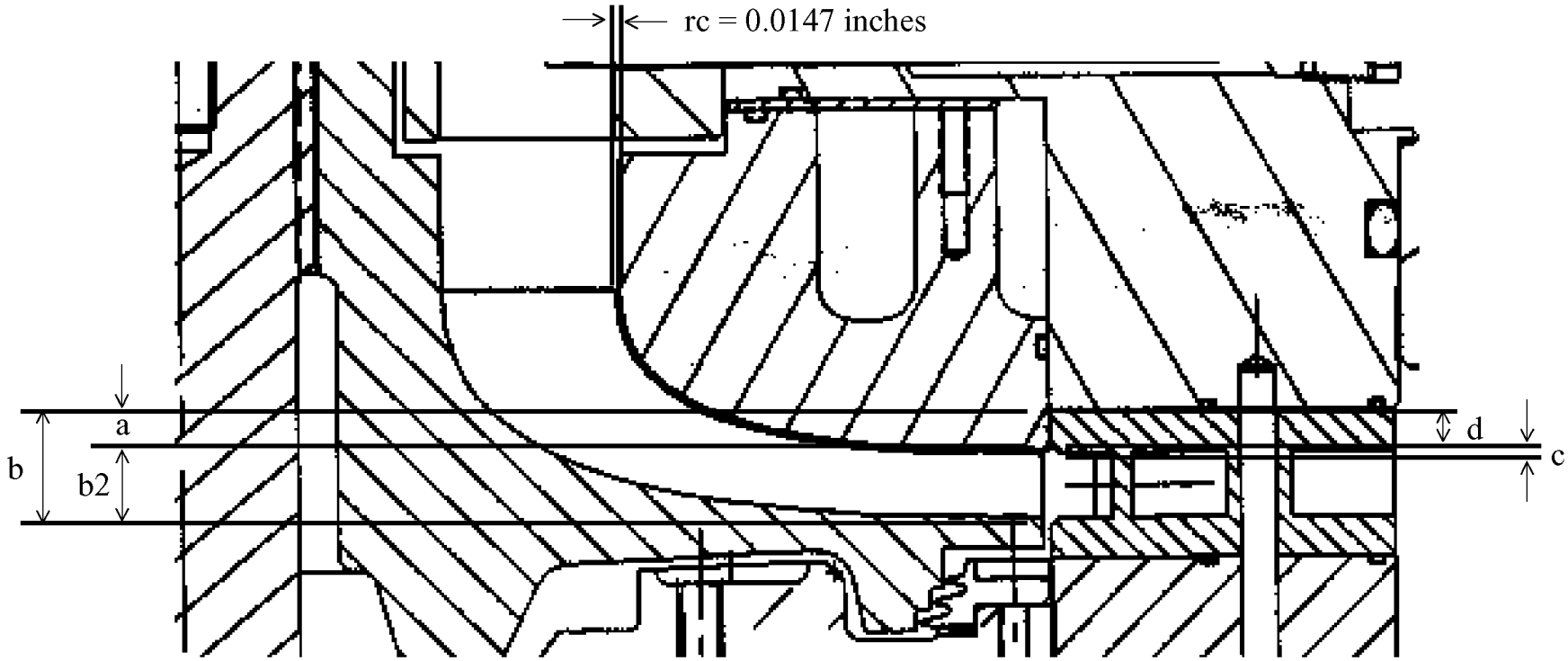
- Control pump operation
  - Speed
  - Flow
  - Inlet pressure
- Maintain test set points
- Pump health monitoring
  - Bearing temperature

Test Article Description

- Modular Design of the Test Article Allows for Use With a Variety of Inlet, Impeller, and Diffuser Configurations
  - Inlet Adapter
  - Inlet Guide Vane Assembly
  - 6+6 Impeller
  - Front Shroud
  - Shims
  - Diffuser



Unshrouded Impeller Test Article Cross Section



Clearance 1
a = 0.3123 inches
b = 0.7526 inches
b2 = b-a = 0.4393 inches
d = 0.2591 inches
c = a-d = 0.0532 inches
%b2 = c/b2 = 12.11%

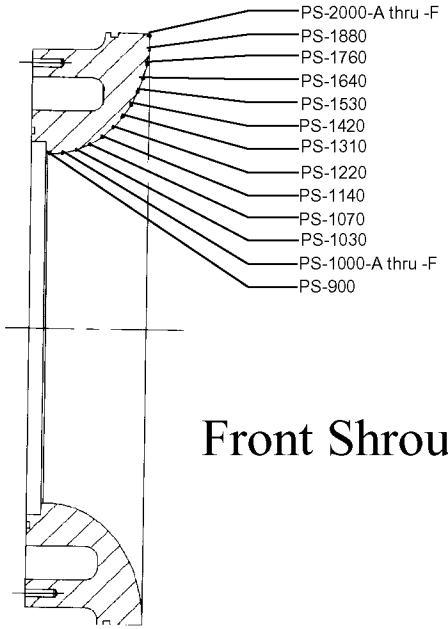
Clearance 2
a = 0.3123 inches
b = 0.7526 inches
b2 = b-a = 0.4393 inches
d = 0.2358 inches
c = a-d = 0.0765 inches
%b2 = c/b2 = 17.41%

Clearance 3
a = 0.3123 inches
b = 0.7526 inches
b2 = b-a = 0.4393 inches
d = 0.3003 inches
c = a-d = 0.0120 inches
%b2 = c/b2 = 2.73%

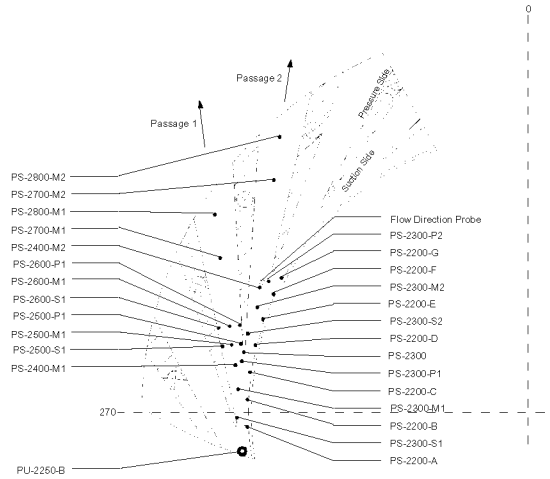
Test Measurements

- Steady-state measurements
  - Surface static pressure taps are grouped into 27 measurement planes
    - Static pressure taps concentrated at: front shroud, diffuser, rear shroud, and discharge housing
  - Total pressure probes are located in the facility inlet and exit spools
  - Flow direction probes are located just downstream of the inlet guide vanes and impeller discharge
  - Facility flow rate and the leakage flows in 2 external metering lines
  - Shaft speed and shaft torque measured directly
  - Water and bearing temperatures measured
  - Dissolved oxygen measured
- Unsteady measurements
  - High frequency pressure transducers located in facility inlet and exit spools
  - Three high frequency pressure transducers located at impeller discharge
  - Single accelerometer mounted on bearing housing

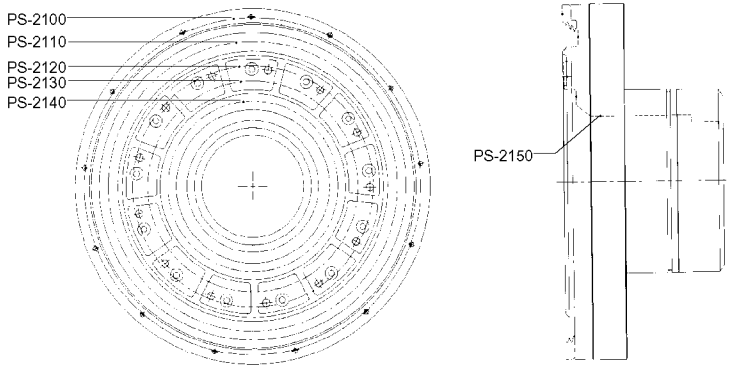
Measurement Locations



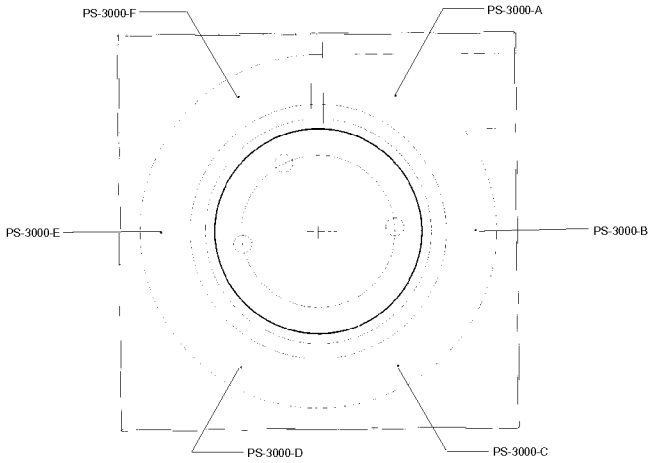
Front Shroud



Diffuser



Rear Shroud

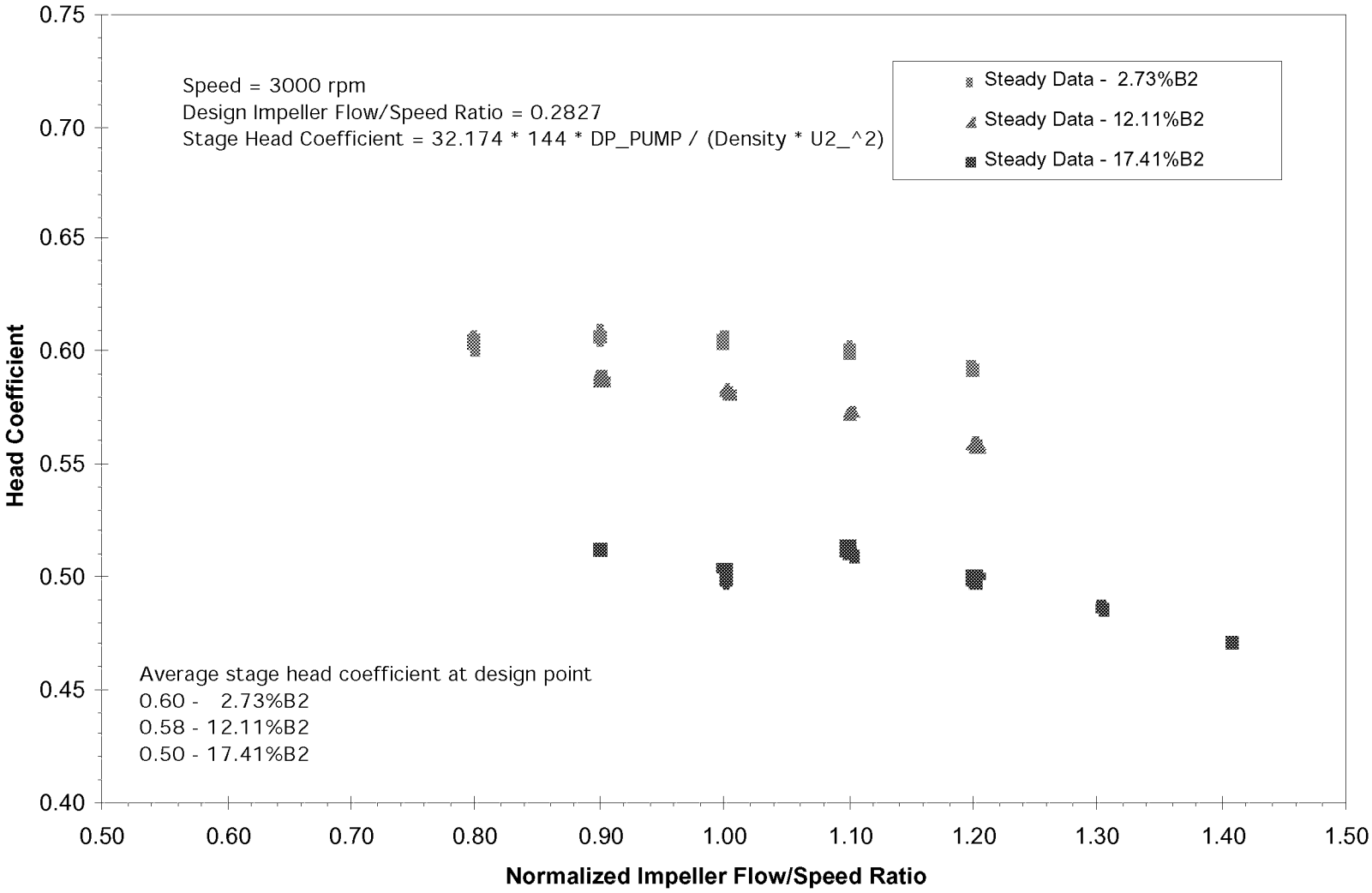


Discharge Collector

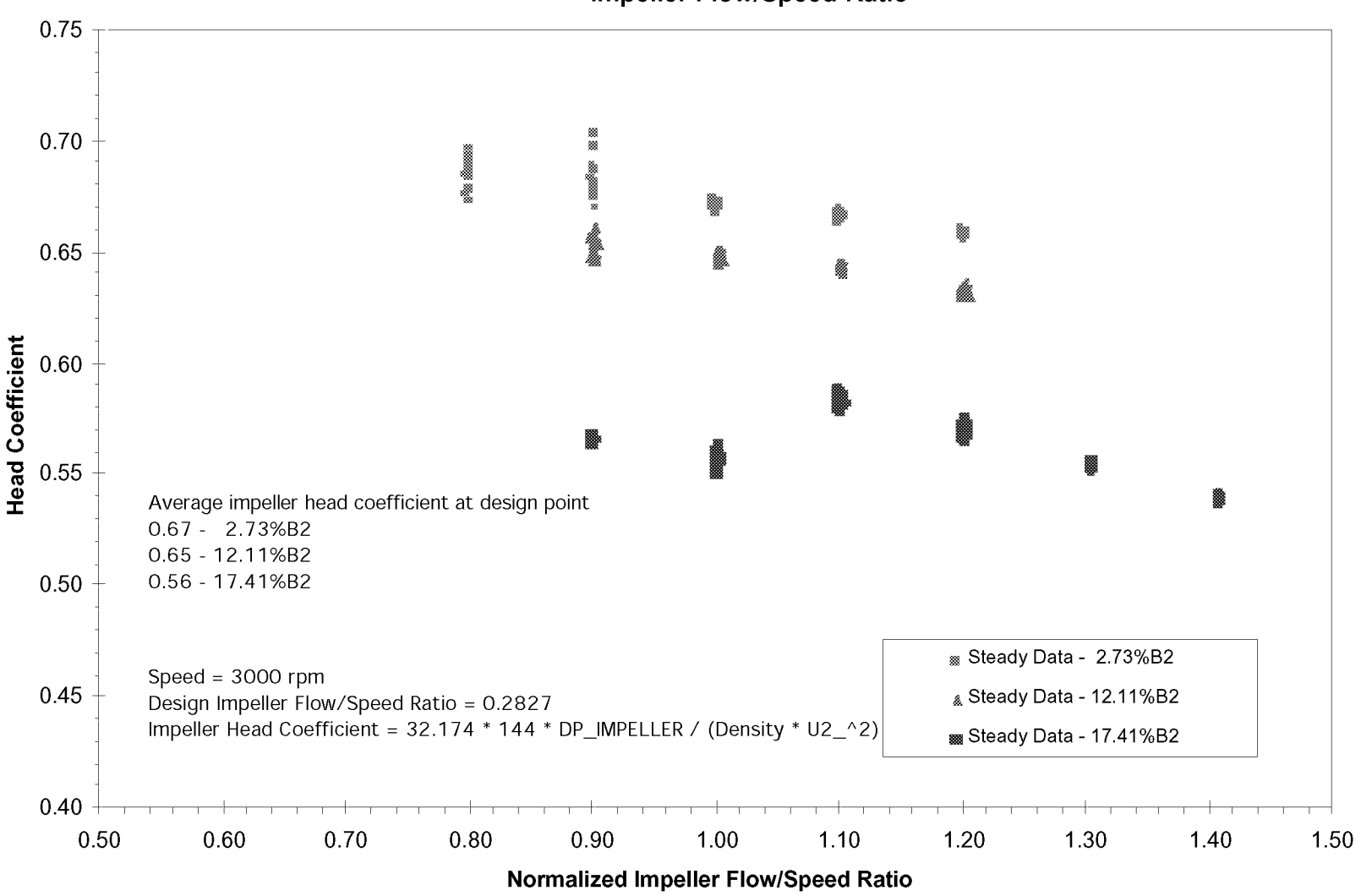
Test Matrix

- Performance evaluated over range of scaled operating conditions at constant shaft speed of 3000 RPM
  - Three test series were conducted to fully map pump performance at different clearances
  - Series included definition of the basic head-flow curve at constant suction specific speed
  - Suction performance mapping across a wide range of flow rates
  - Unsteady pressures and accelerations were recorded during inlet pressure and speed ramps at selected flow coefficients

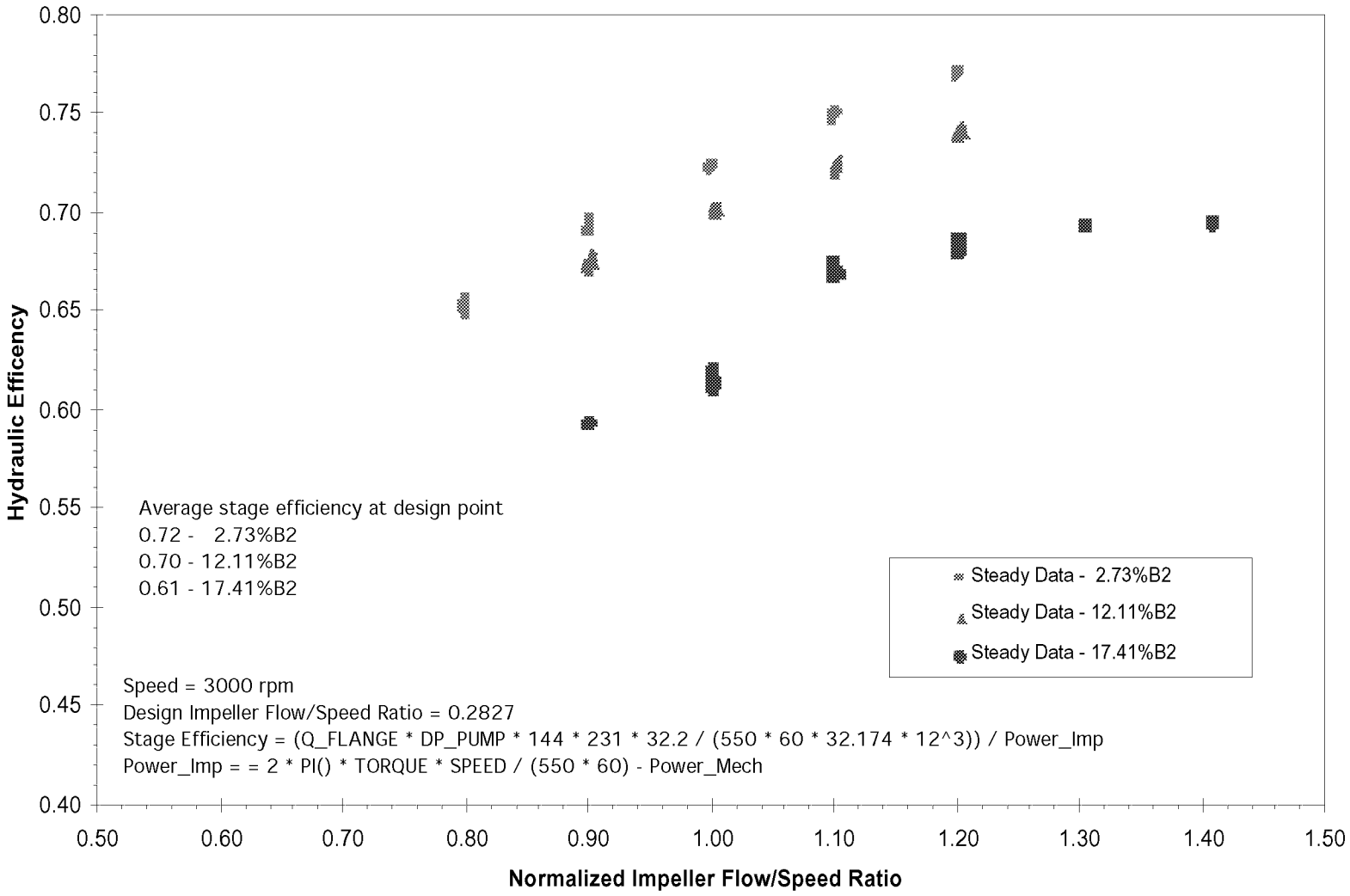
Stage Head Coefficient



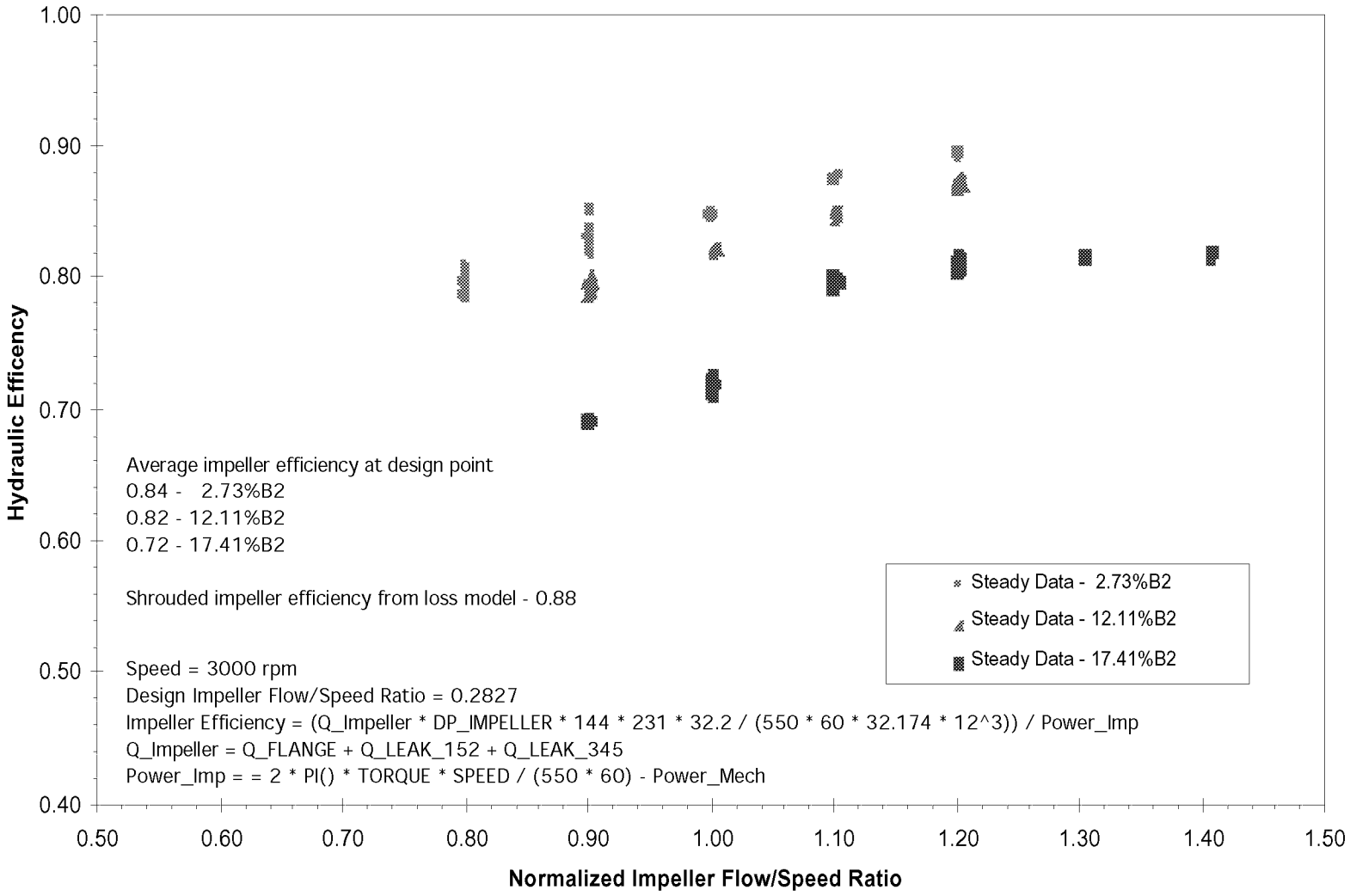
Impeller Head Coefficient



Stage Efficiency



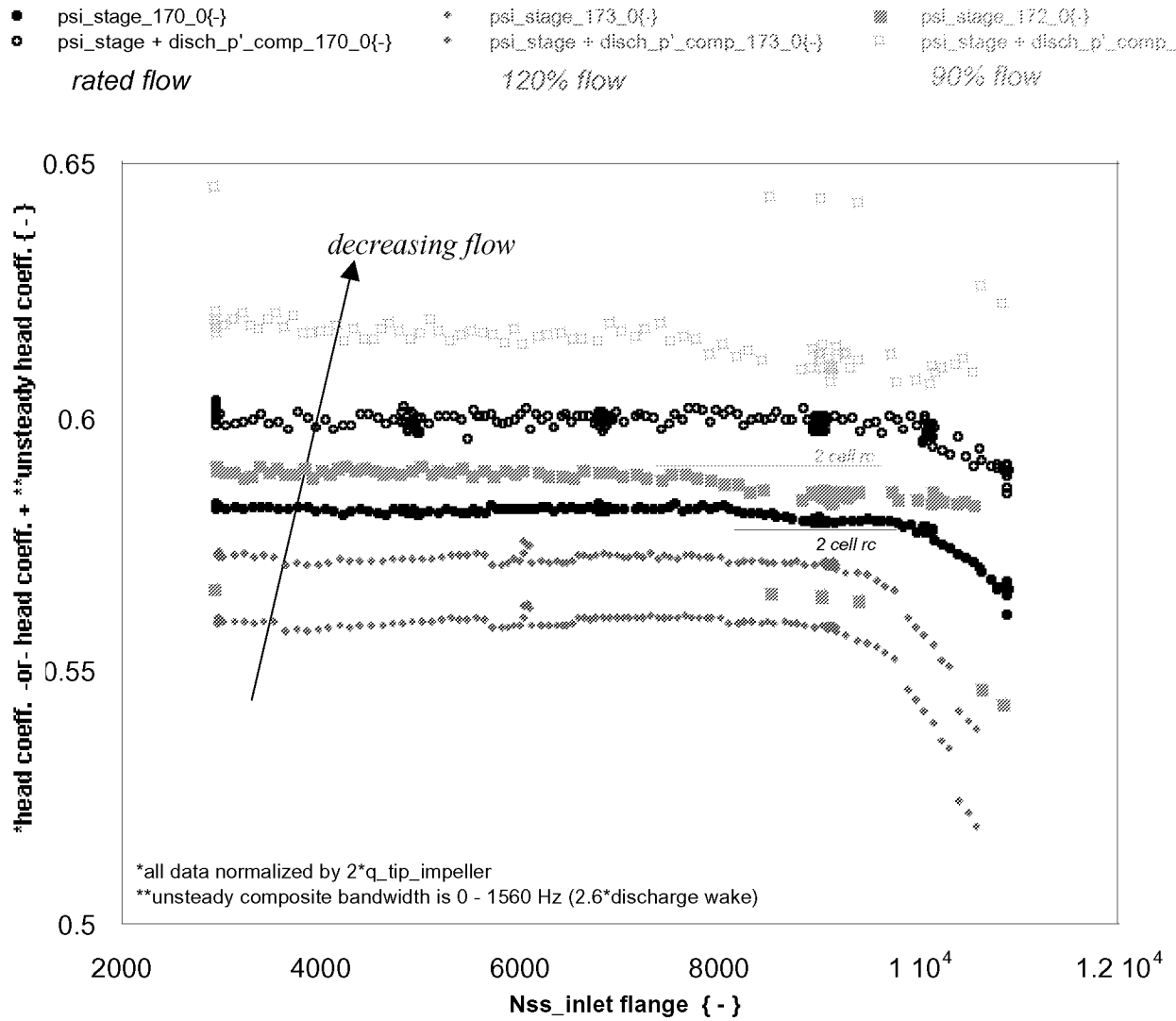
Impeller Efficiency



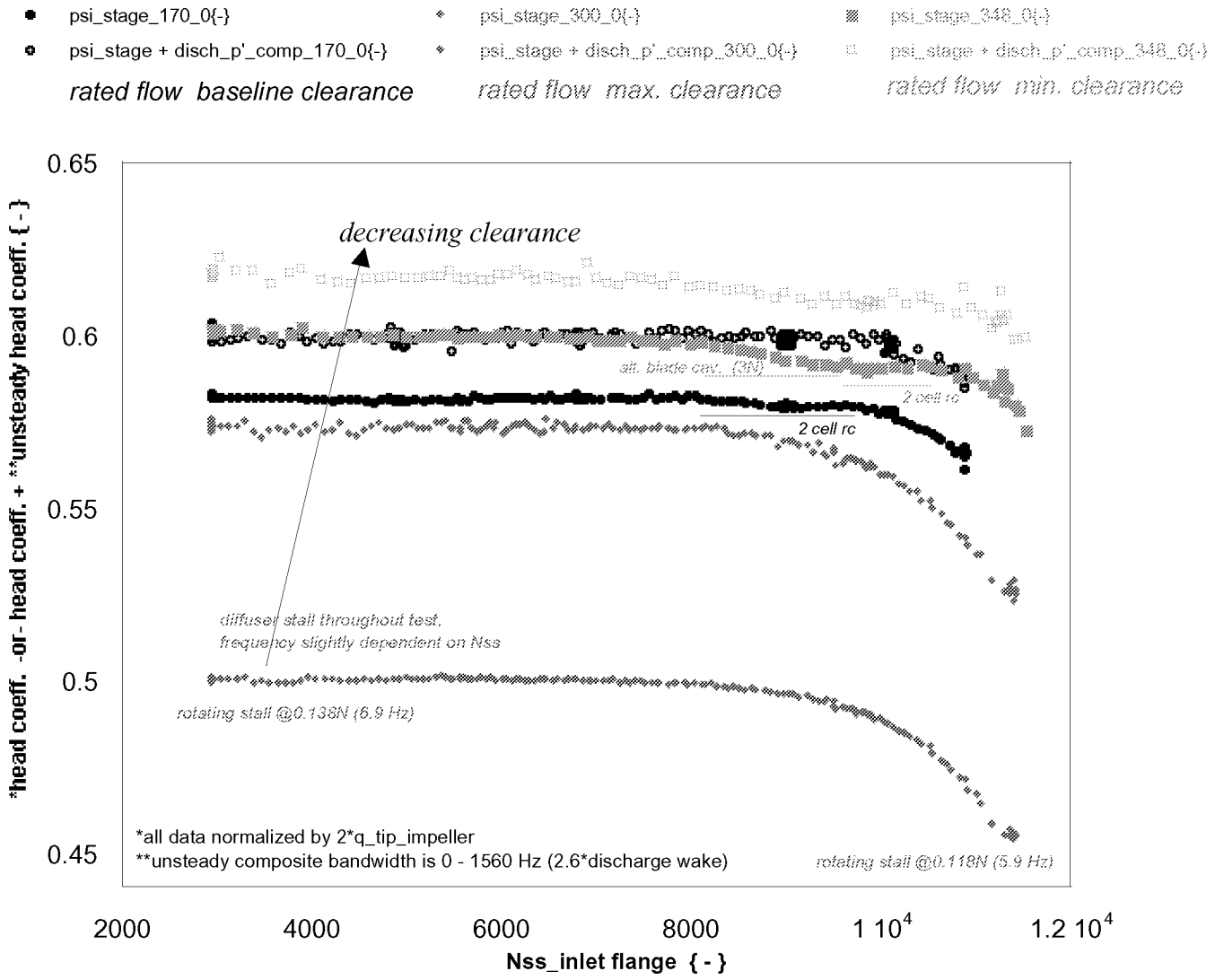
Unsteady Data Overview

- determine impeller / diffuser fluctuating pressure sensitivity to tip clearance
  - over Nss
  - across Q/N
  - correlate unsteady data to stage performance
- identify / map unsteady flow features which could inhibit the development of unshrouded pump technology
  - rotating diffuser / impeller stall
  - rotating cavitation
  - rotor / stator interaction loads (synchronous - impeller wake)

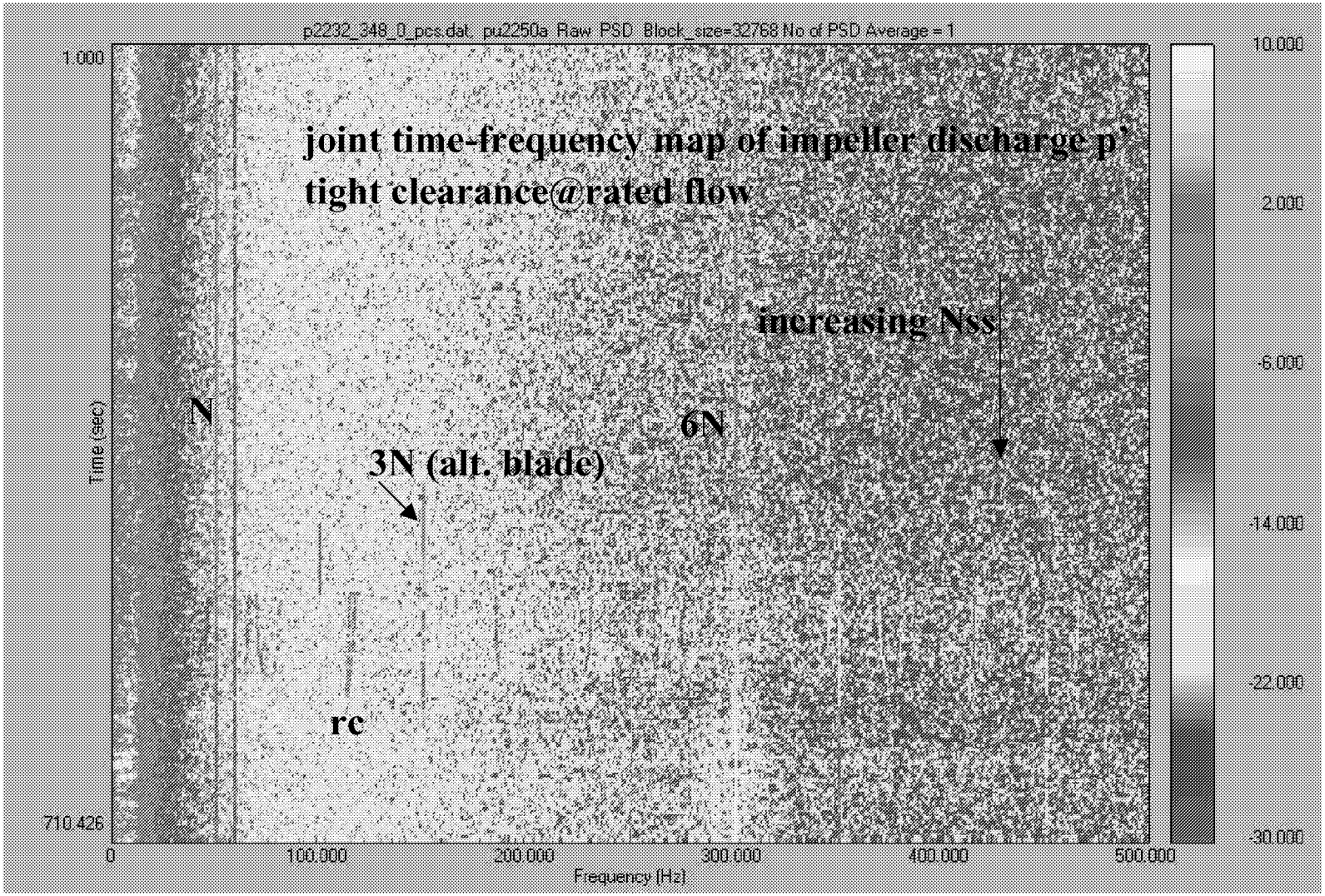
Unsteady Data Overview - baseline clearance



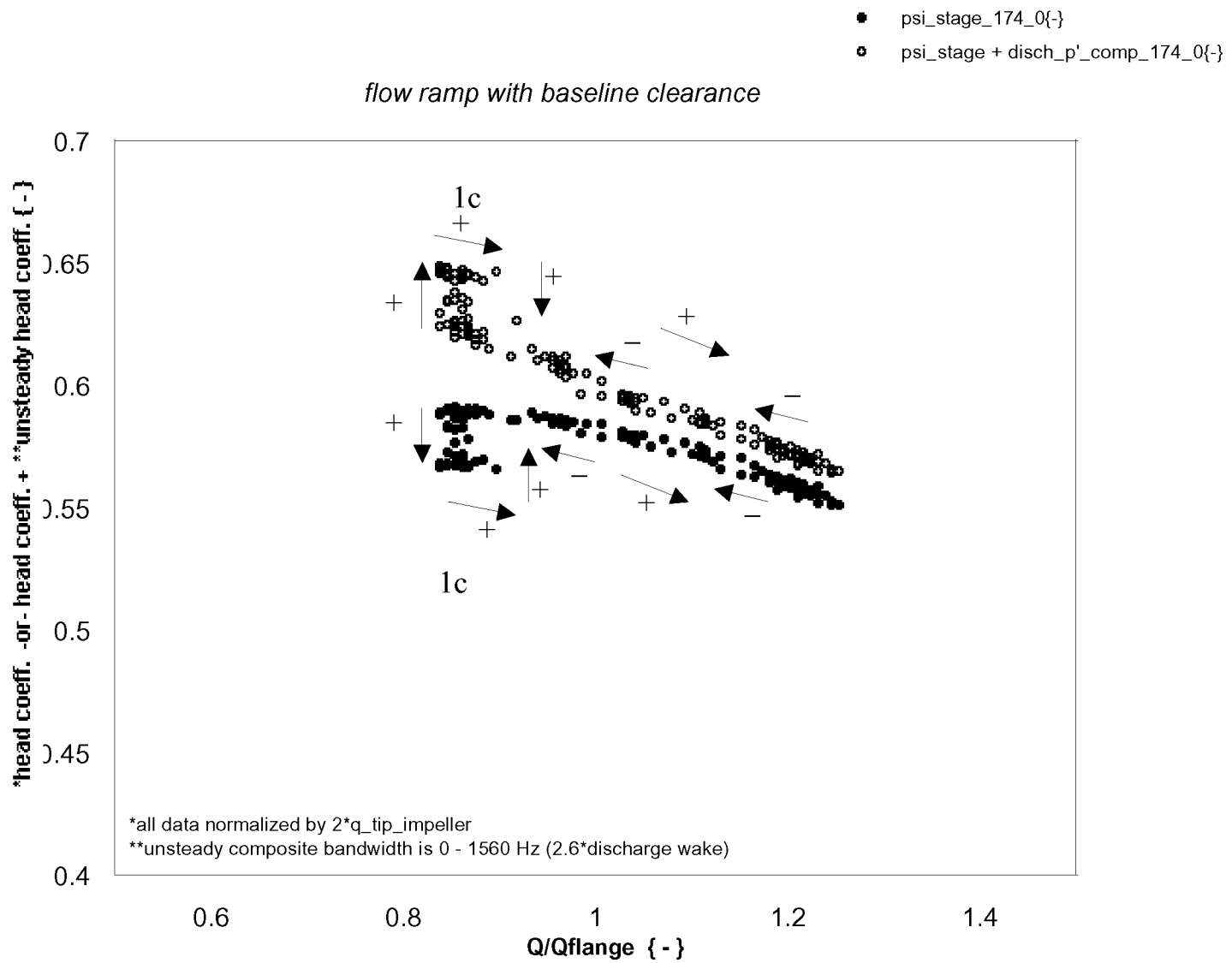
Unsteady Data Overview - across build (rated flow)



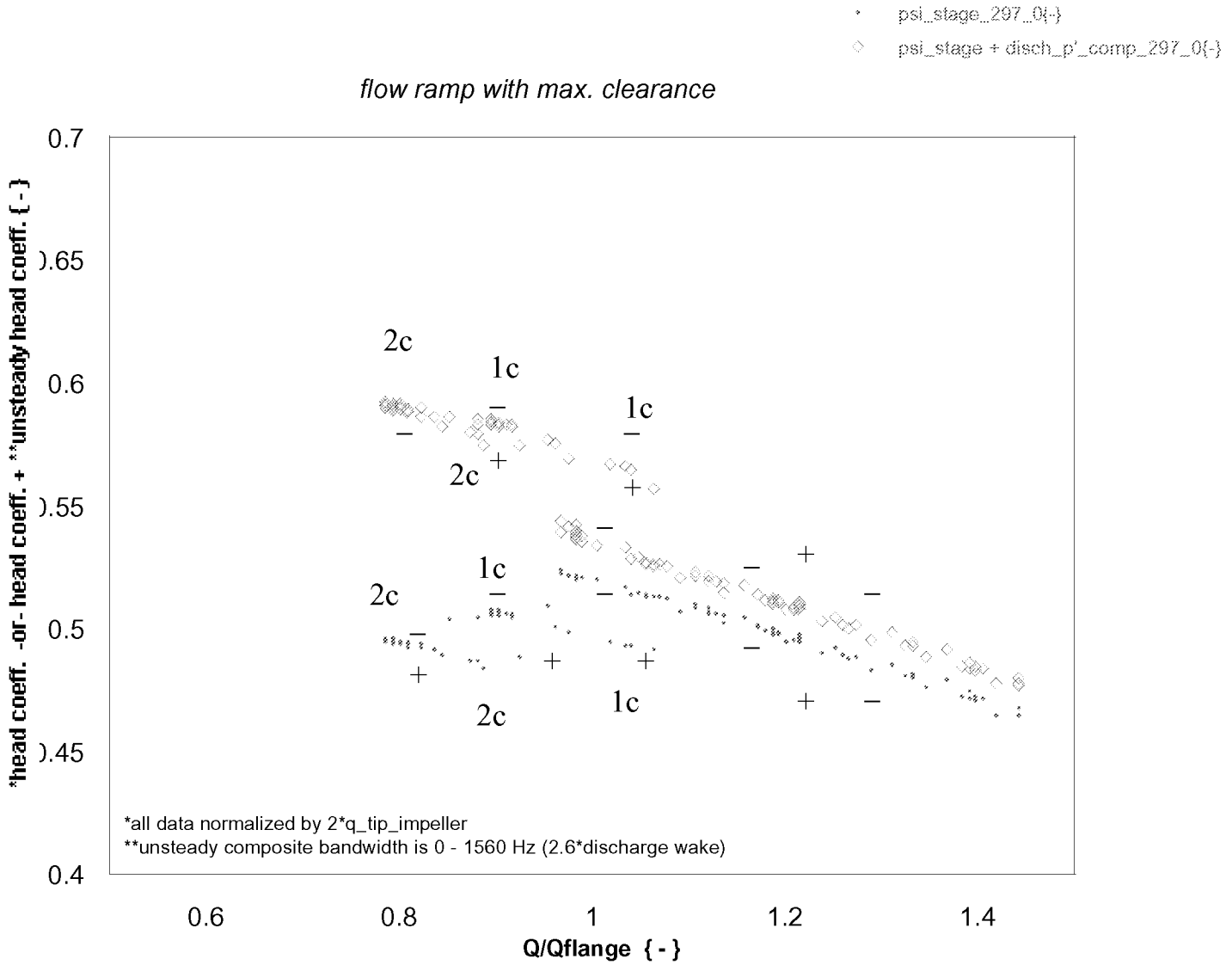
Unsteady Data Overview - cavitation induced oscillations



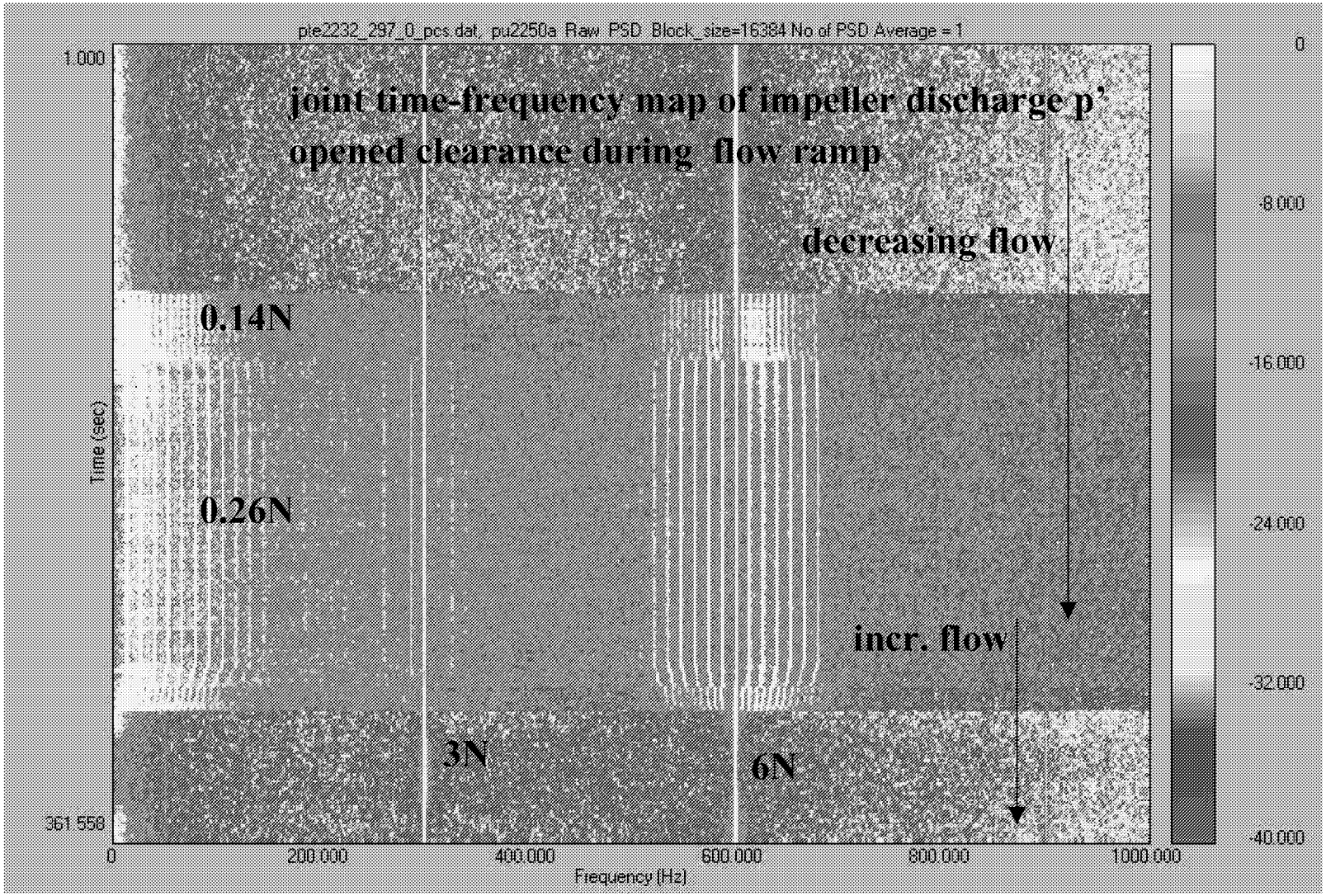
Unsteady Data Overview - flow excursion - baseline clearance



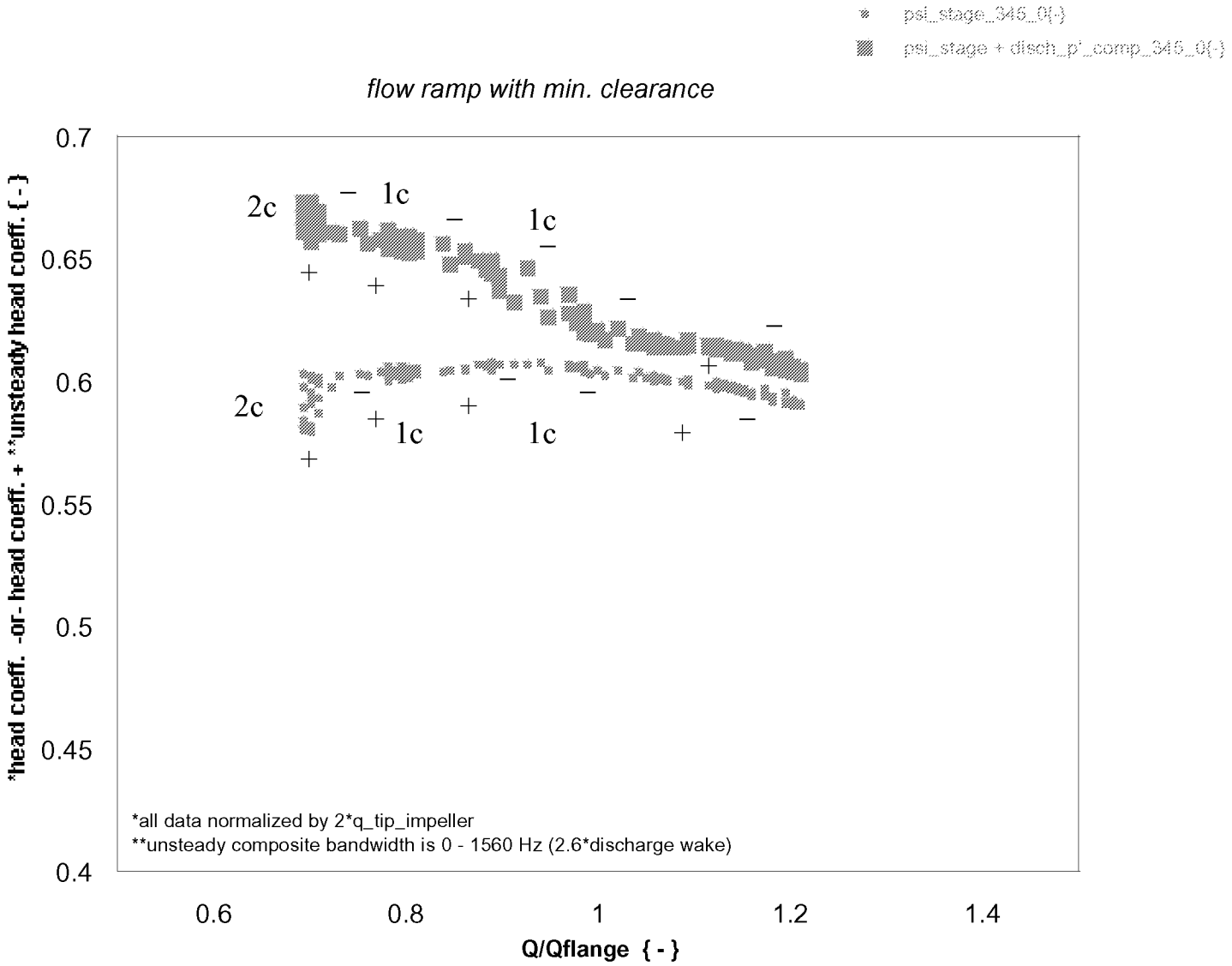
Unsteady Data Overview - flow excursion - opened clearance



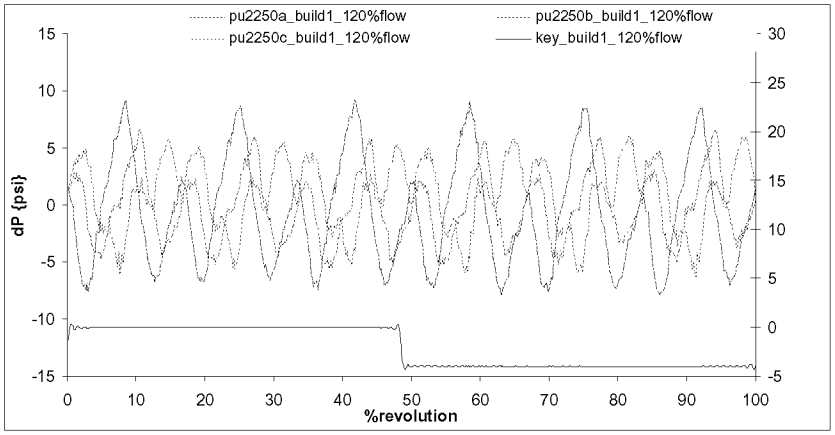
Unsteady Data Overview - rotating stall



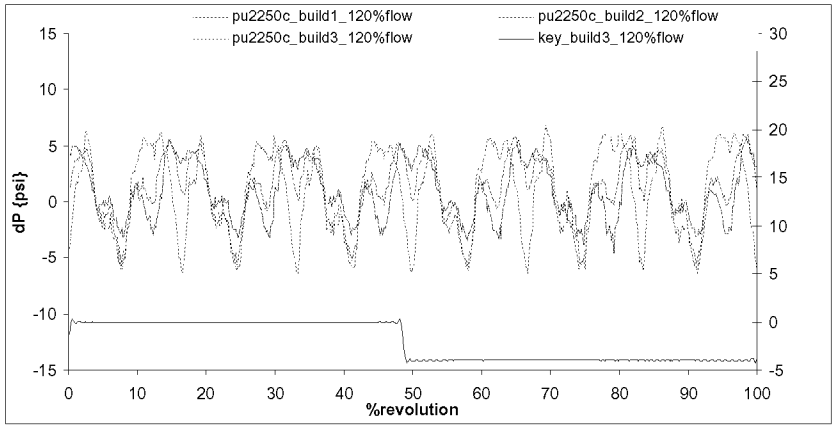
Unsteady Data Overview - flow excursion - tight clearance



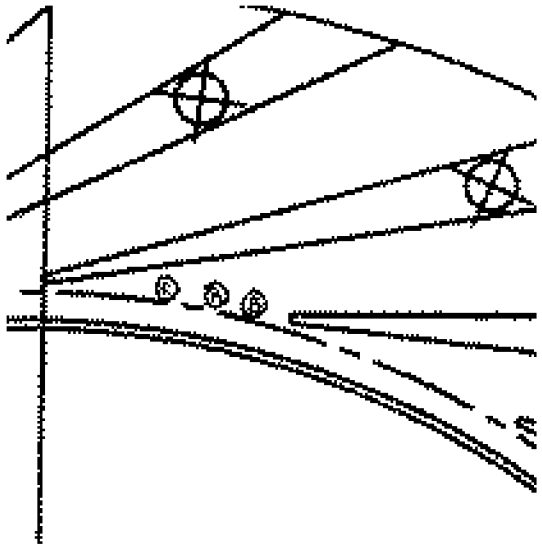
Unsteady Data Overview - rotor_stator interaction



120% flow across locations

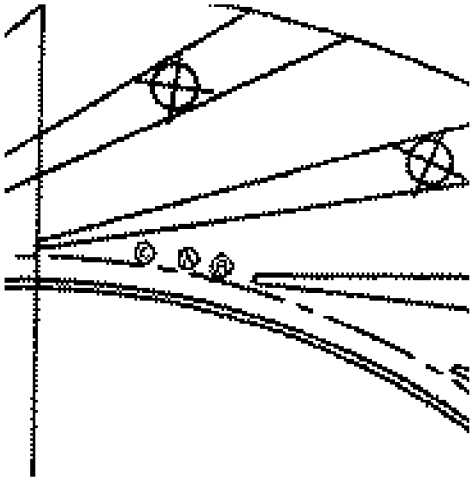


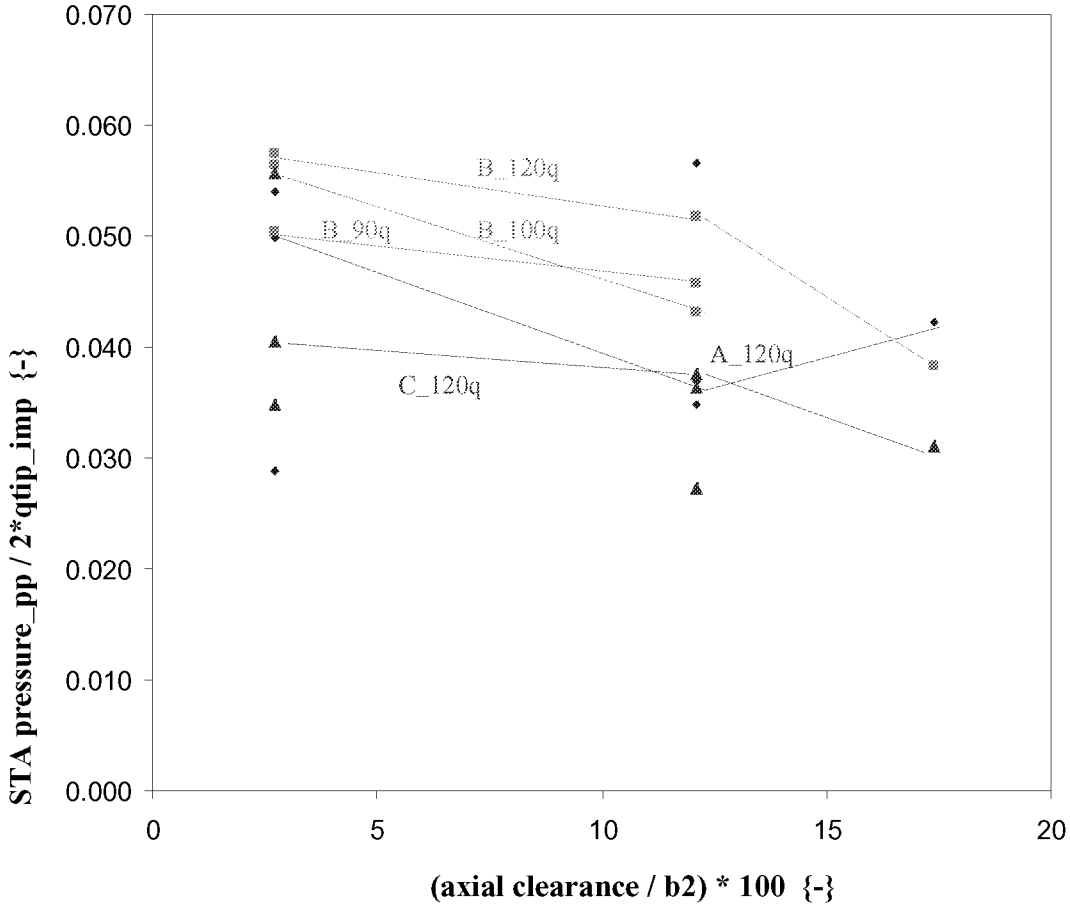
120% flow across builds_location C (vane l.e. suction)



- map impeller wake across diffuser channel versus Q/N and axial clearance
- use synchronous time averaging process
- build data set for time-accurate CFD

Unsteady Data Overview - rotor_stator interaction





Unsteady Data Summary

- determine impeller / diffuser fluctuating pressure sensitivity to tip clearance
  - Nss not a major influence on overall composite unsteady pressure at impeller discharge
  - Q/N excursions identified both single and dual-cell rotating stall at impeller / diffuser interface
    - hysteresis (w/r to flow) and axial clearance dependence identified
  - unsteady data to stage performance correlation (head loss) most pronounced during rotating stall with some correlation during rotating cavitation (2-cell) and alternate blade (3N) cavitation
- identify / map unsteady flow features which could inhibit the development of unshrouded pump technology
  - rotating diffuser / impeller stall mapped
  - rotating and alternate-blade (attached) cavitation mapped
  - rotor / stator interaction loads characterized versus Q/N and axial clearance