# Final Direct Surge Control Report & GMRC Project Plan

## Increased Flexibility of Turbo-Compressors in Natural Gas Transmission Through Direct Surge Control

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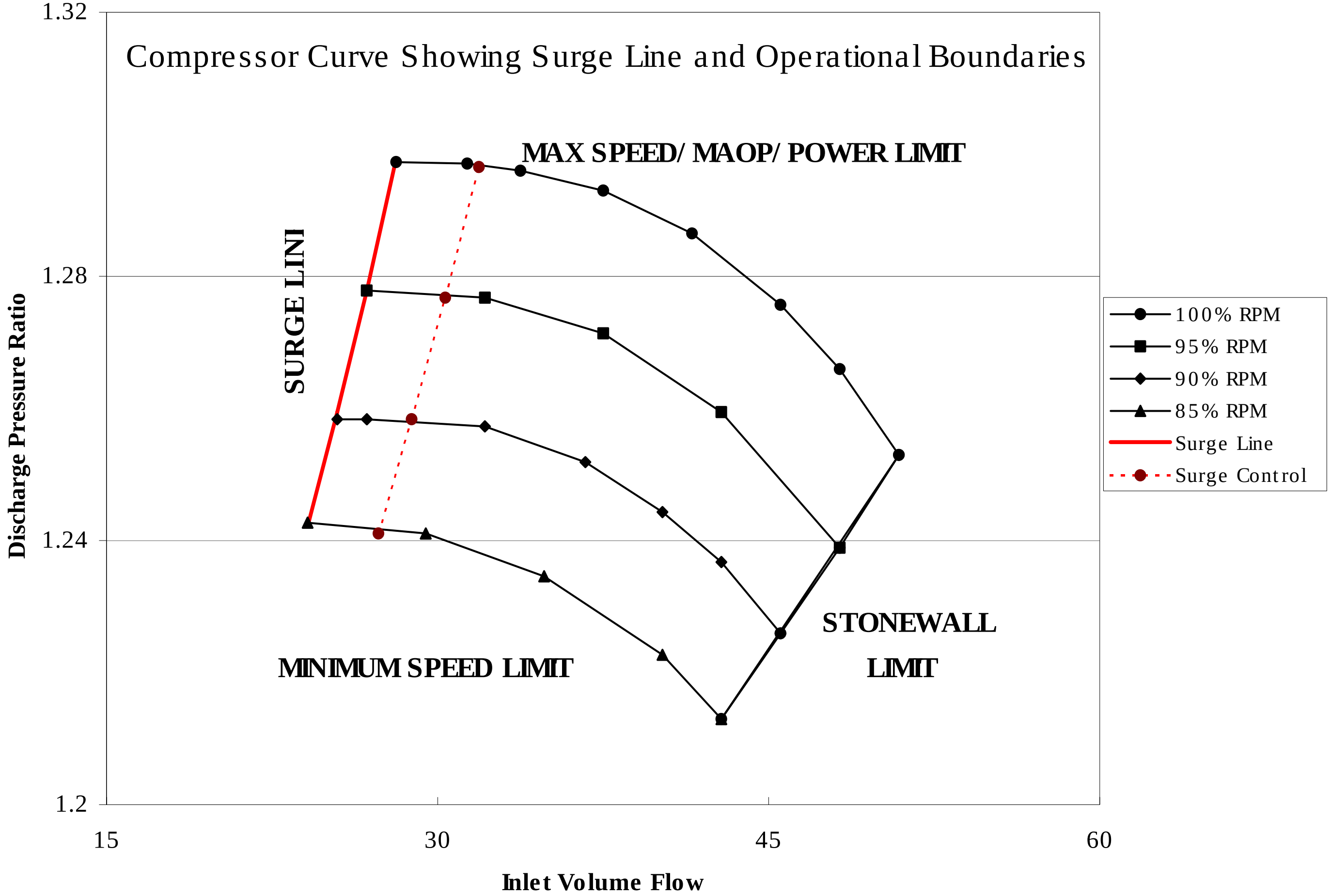
# Project Identification

- This DOE project was directed and funded by
  - DOE's Office of Fossil Energy, the
  - National Energy Technology Laboratory, and the
  - Strategic Center for Natural Gas and Oil, in the
  - Delivery Reliability Program, as part of the
  - Natural Gas Infrastructure Program.
- The Co-funders are the Gas Machinery Research Council and Siemens Energy and Automation
- Other participants were Duke and El Paso Energy and Solar Turbines.
- Conducted by Southwest Research Institute

# Centrifugal Compressor Operating Map

- Surge is a potentially damaging instability.
- Surge limits low flow operations.
- Current controls results in unnecessary recycle flow.



# Objectives

- To develop an internal surge control sensor and an associated surge control system that will allow reduced surge margins, increased range and flexibility of operation, and safe minimization of the energy and costs of avoiding surge in pipeline centrifugal compressors.
- To meet the needs of the natural gas industry for improved surge control.

# What happens before and during surge?

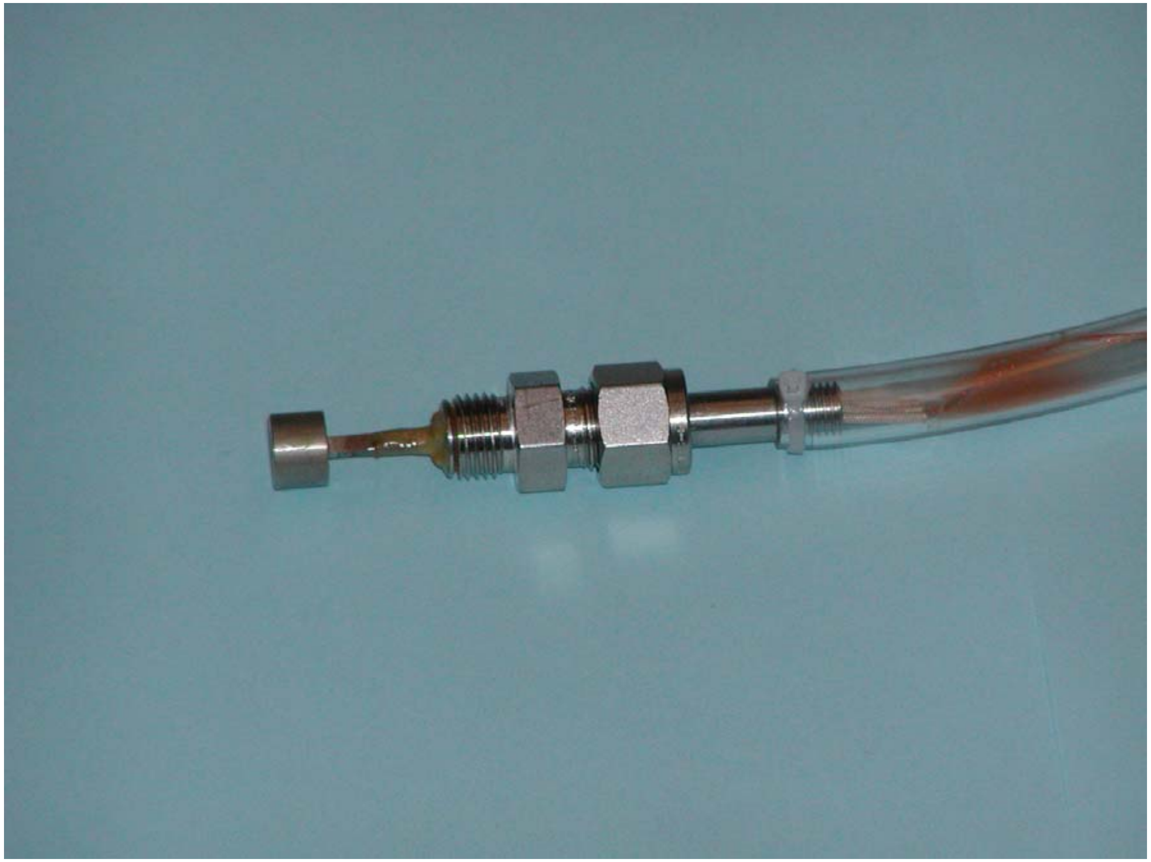
- In some, but not all cases, surge is preceded by unsteady pulsation and vibrations due to stall.
- In other cases, there are no vibrations, pulsation, or warnings and surge occurs suddenly.
- Surge is a complete collapse of compressor flow and results in gas travelling backwards through a forward spinning impeller.
- Surge is energetic and can cause damage to thrust bearings, seals, impellers, etc.
- A flow re-circulation occurs at the impeller inlet as identified by previous GMRC research

# Industry Specifications - General

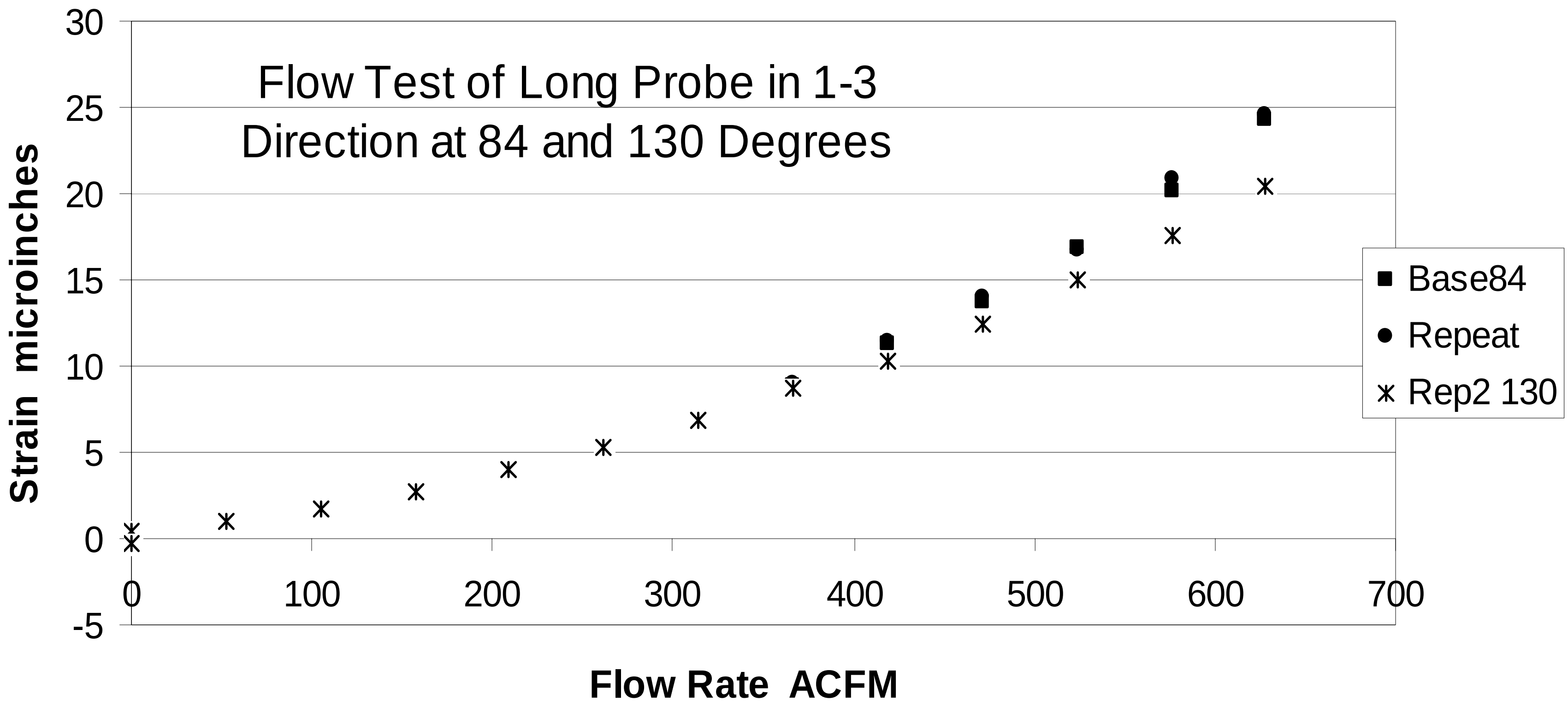
- The sensor is to be simple, rugged, sensitive, cost effective, manufacturable, installable, and able to detect the nearness of surge in a useful manner.
- The controller is to use the nearness to surge signal and incorporate algorithms to control the compressor in a flexible manner, with a minimum safe surge margin, and increased efficiency in response to the operating requirements.

# Design Process and Typical Drag Probe

- Size probe for max and min velocity & force
- Size bending beam for support & strain sensitivity
- Predict & avoid vortex & mech. natural frequencies
- Design probe holder & wire way
- Iterate on design until all is OK

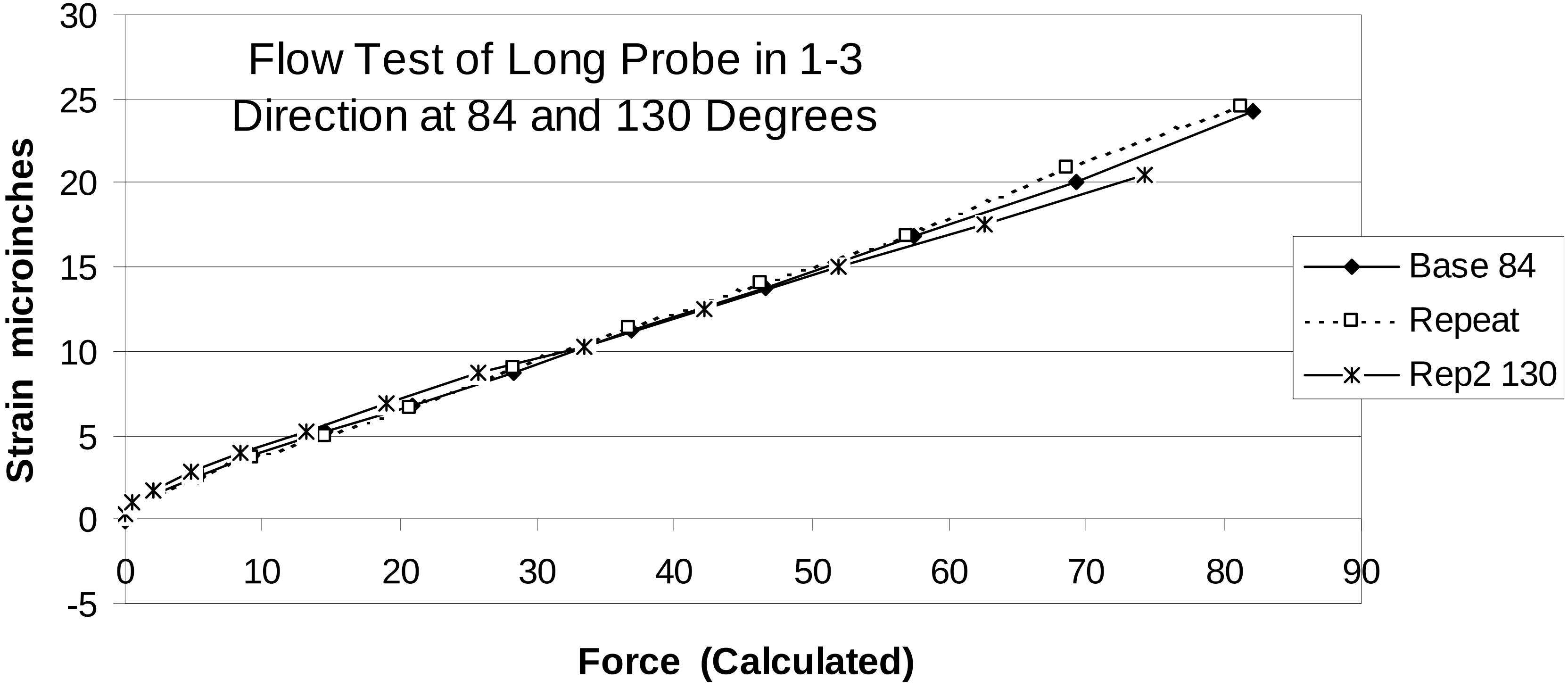


# Flow Test Results for a Drag Probe




One Direction Flow at Two Temperatures

# Flow Test Results as Force vs. Strain

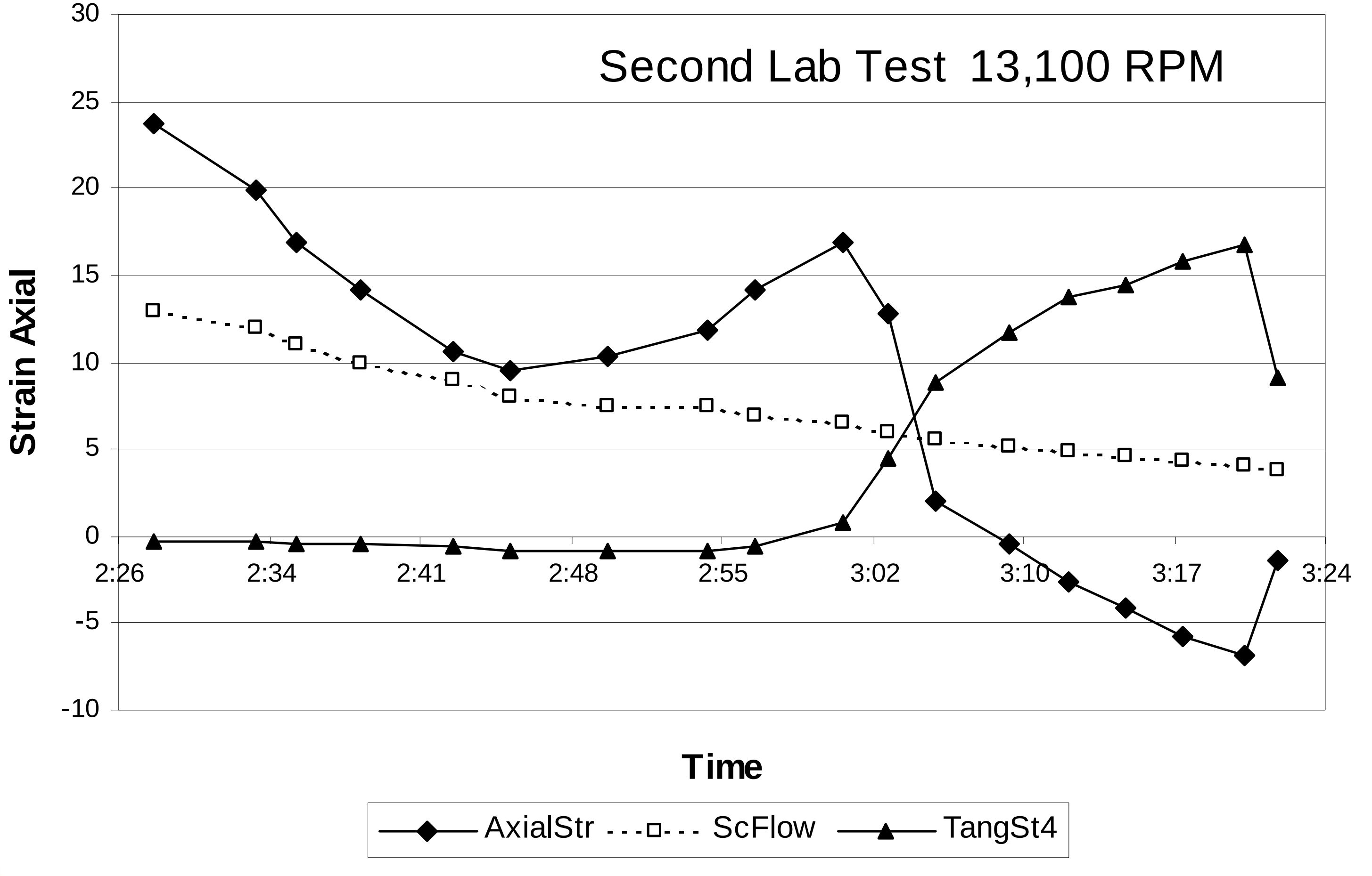



Flow calibrations are not necessary for every probe

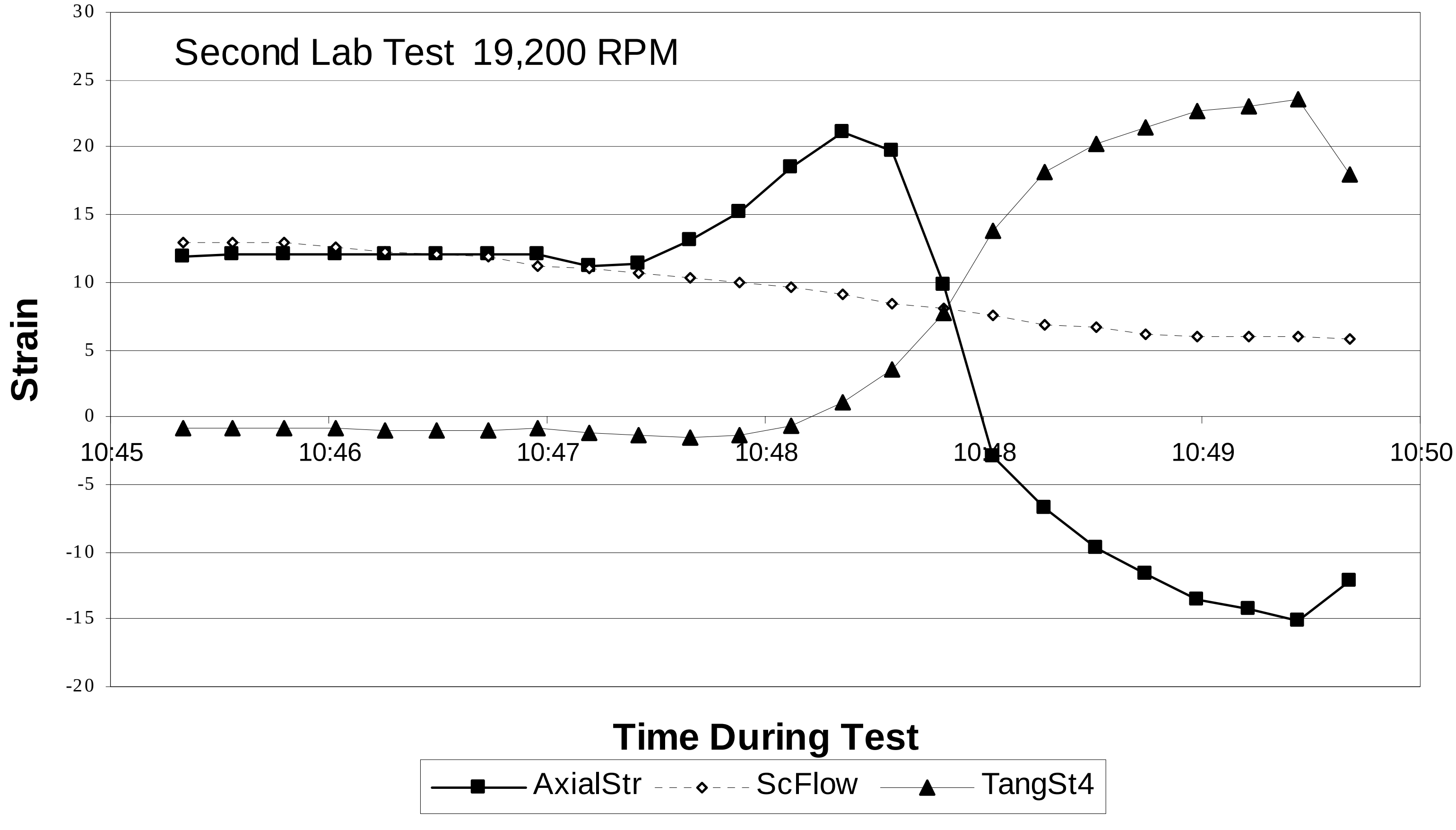
# A Finding from the Test Program

- Direct Surge Control in the present implementation with a probe at the impeller inlet is applicable for modern 3D impellers and not for older units with 2D impellers where the blades are recessed from the inlet.
- It is estimated that between 66 and 80 percent of pipeline centrifugal compressors in use are of the modern 3D design.

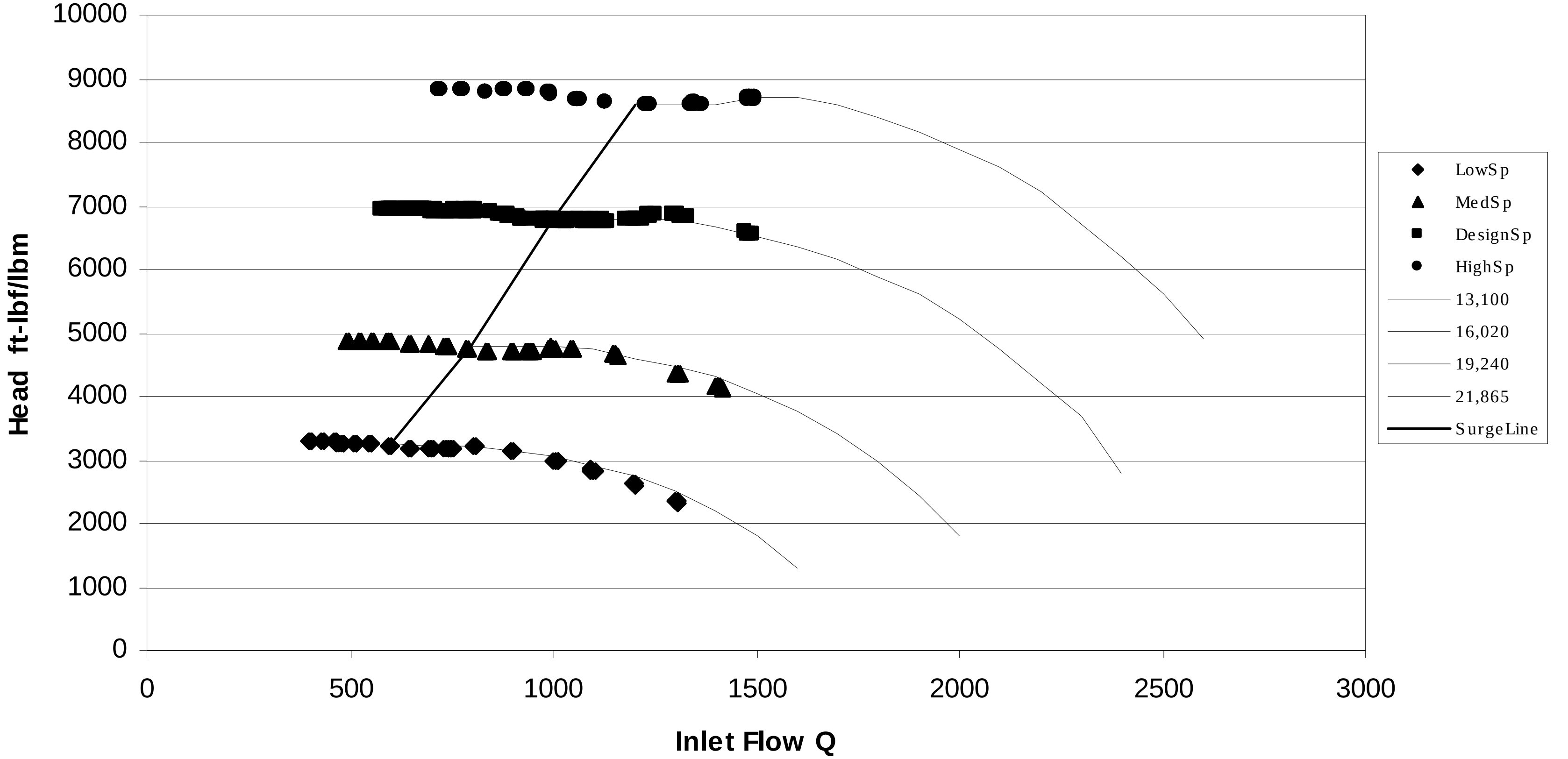
# Laboratory Compressor Test at Low Speed Axial & Tangential Strain with Scaled Flow



# Laboratory Compressor Test at High Speed Axial & Tangential Strain with Scaled Flow

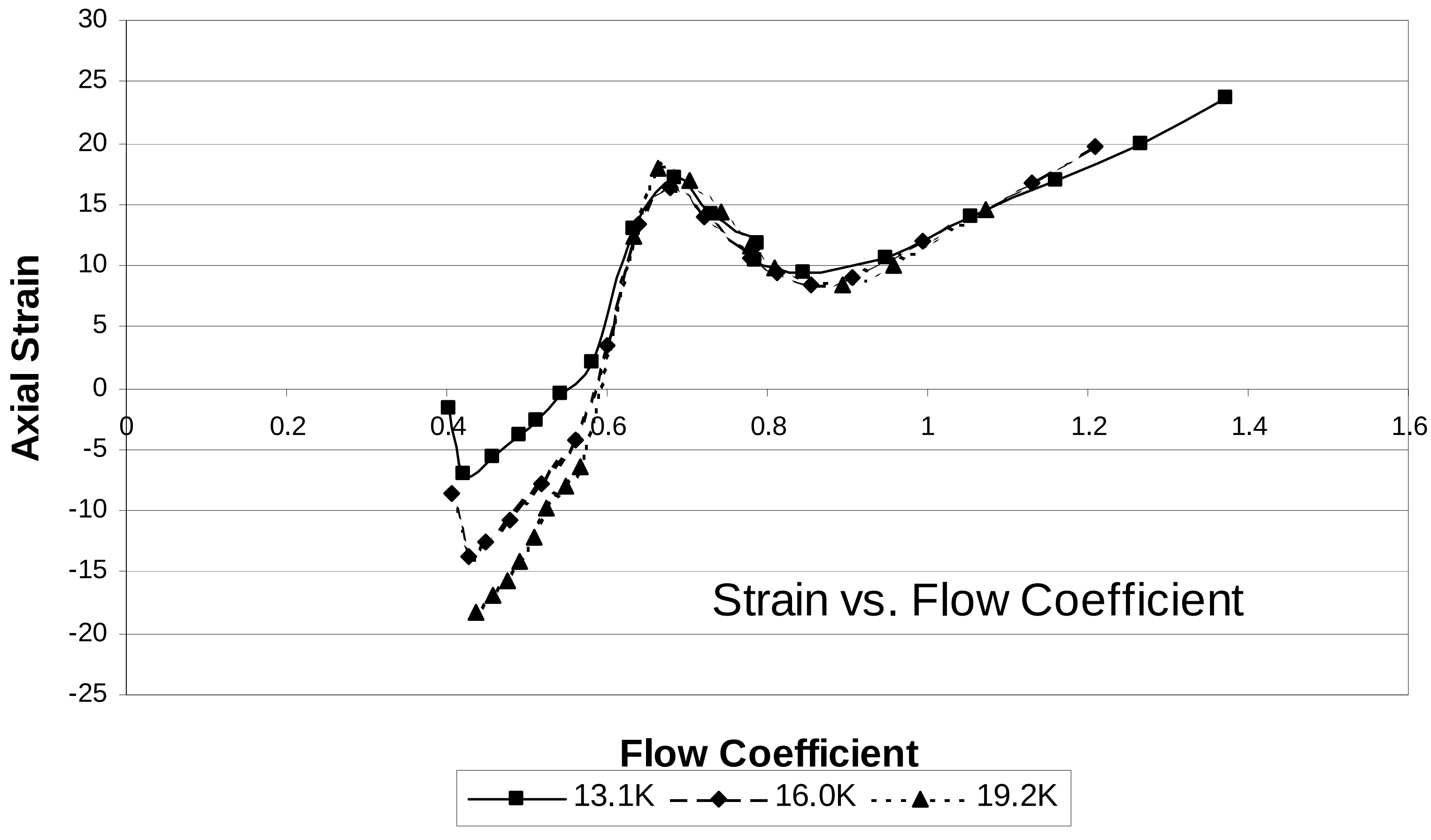


# Increased Range on the Laboratory Unit Map with Use of Direct Surge Detection

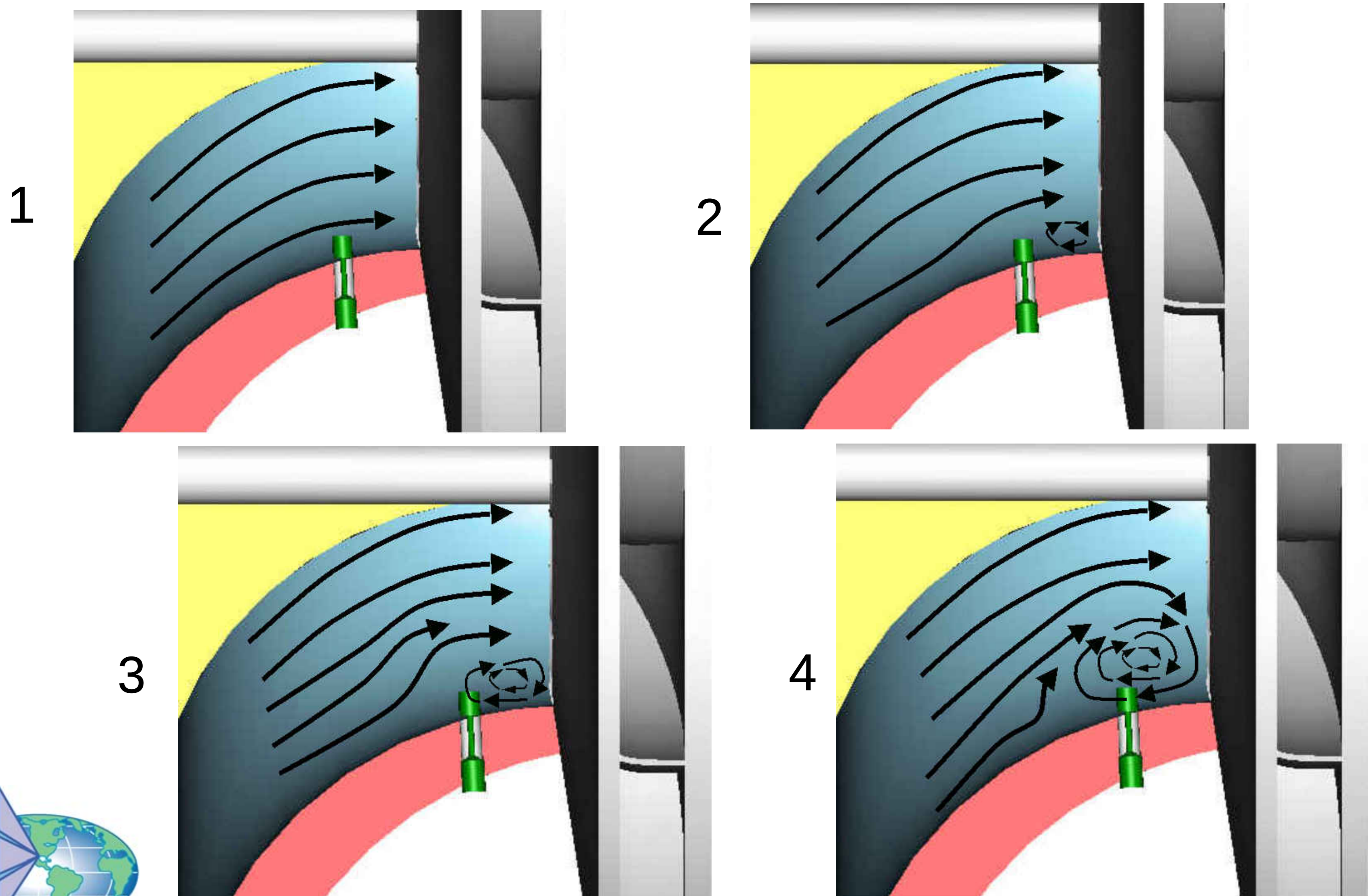



Turndown by Surge Line = 47%, by Surge Probe = 68%

# Plot of Axial Strain Changes as a Function of Flow Coefficient for Laboratory Tests



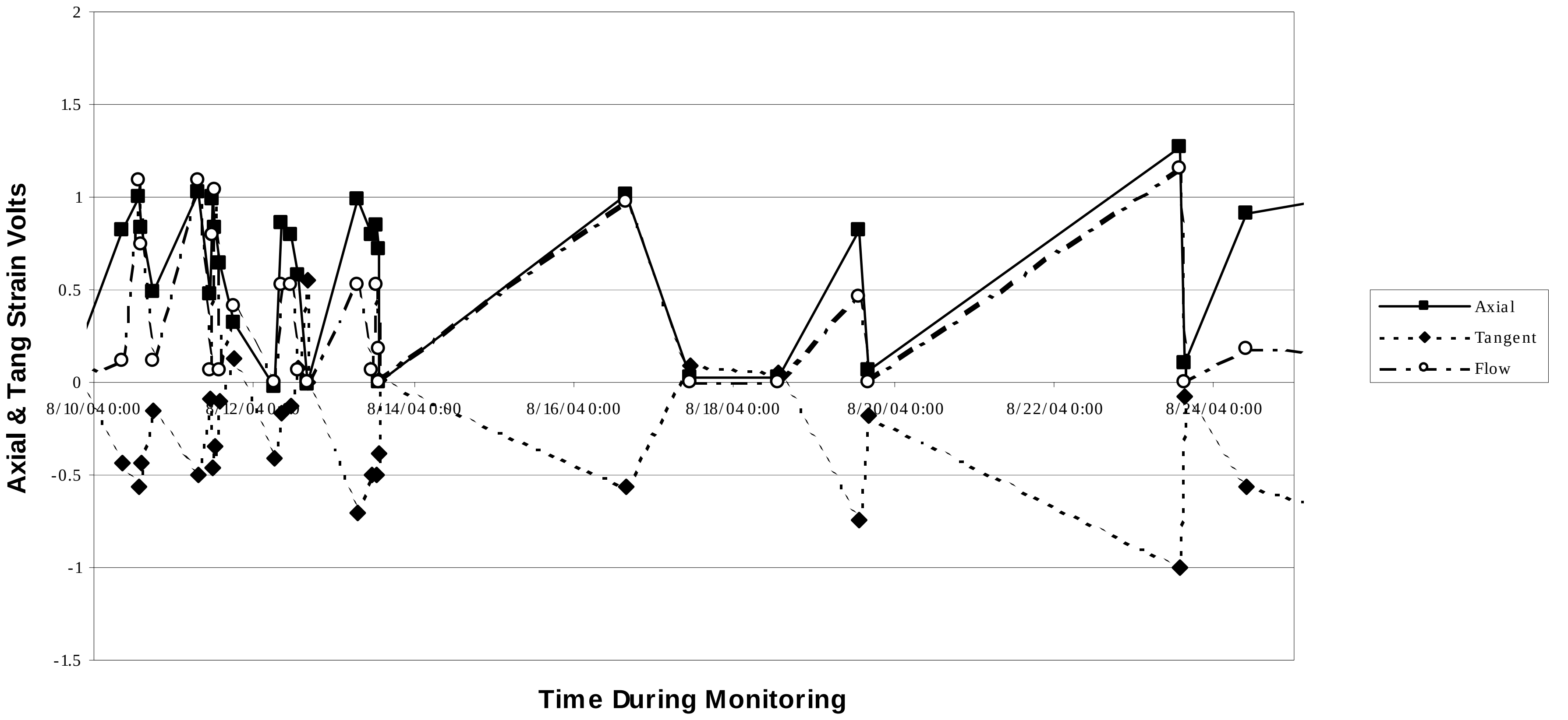
# Diagram of Flow Vectors as Surge is Approached with a Drag Probe Location



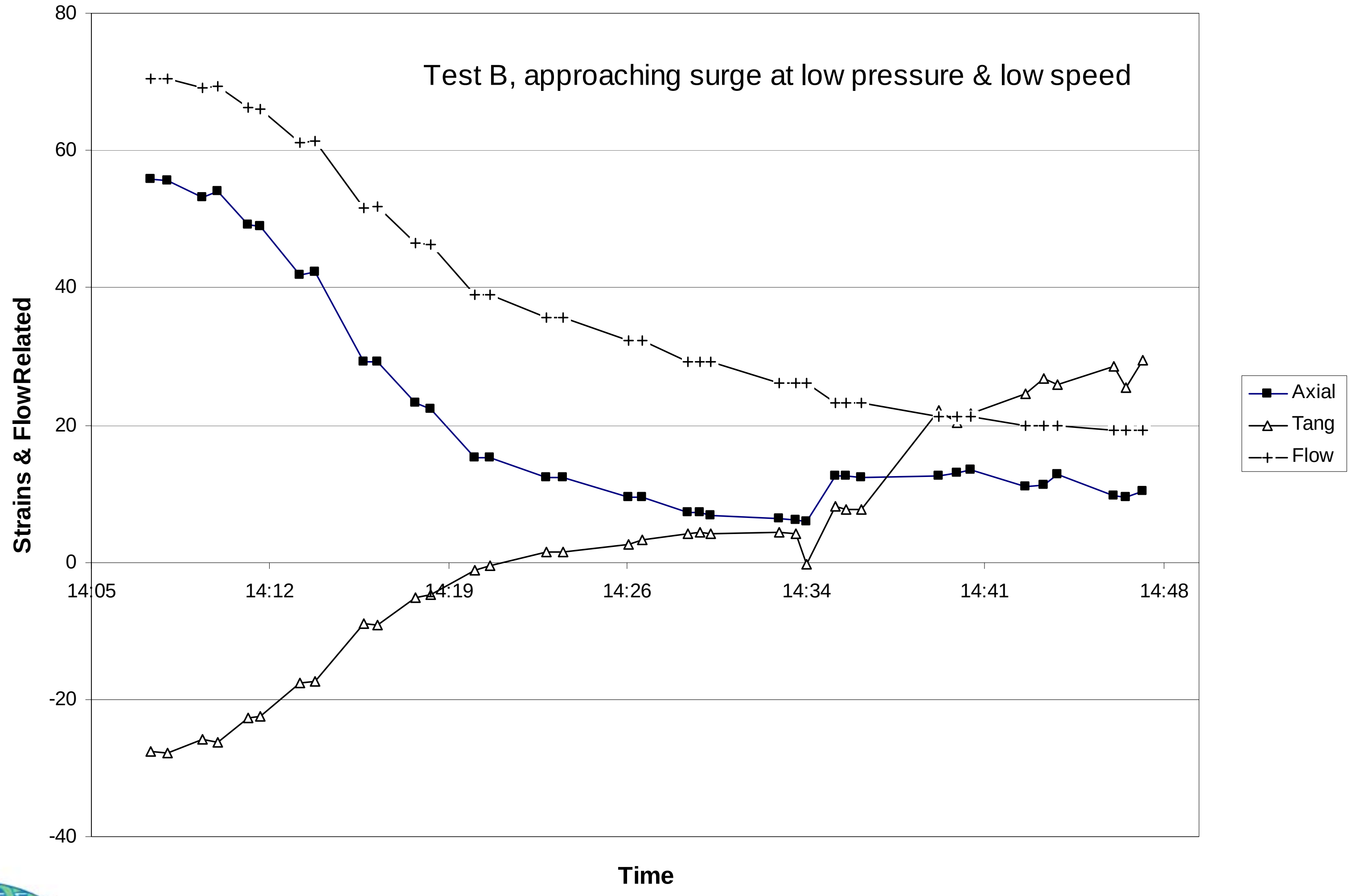
# Requirements for Direct Surge Detection

- The route of the wire within and leaving the compressor must be protected and secure. Solid core wires in a quality compression fitting are needed.
- The output of the strain gauge bridge from the probe must be stable and repeatable.
- The strain gauge circuit should automatically balance when a compressor is shut down for a period of time.

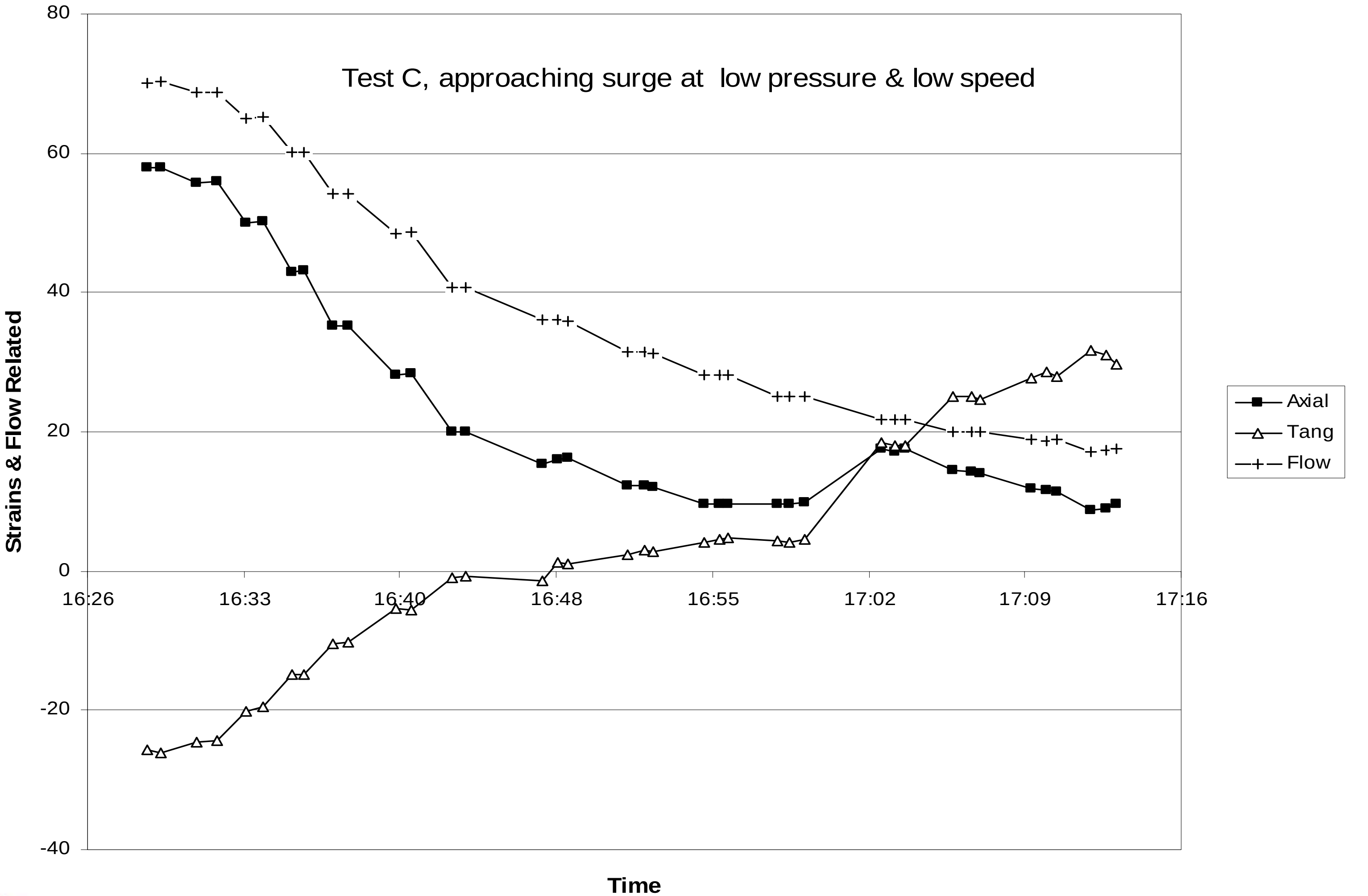
# Long-Term Stability of Strain Signals with Operational Changes



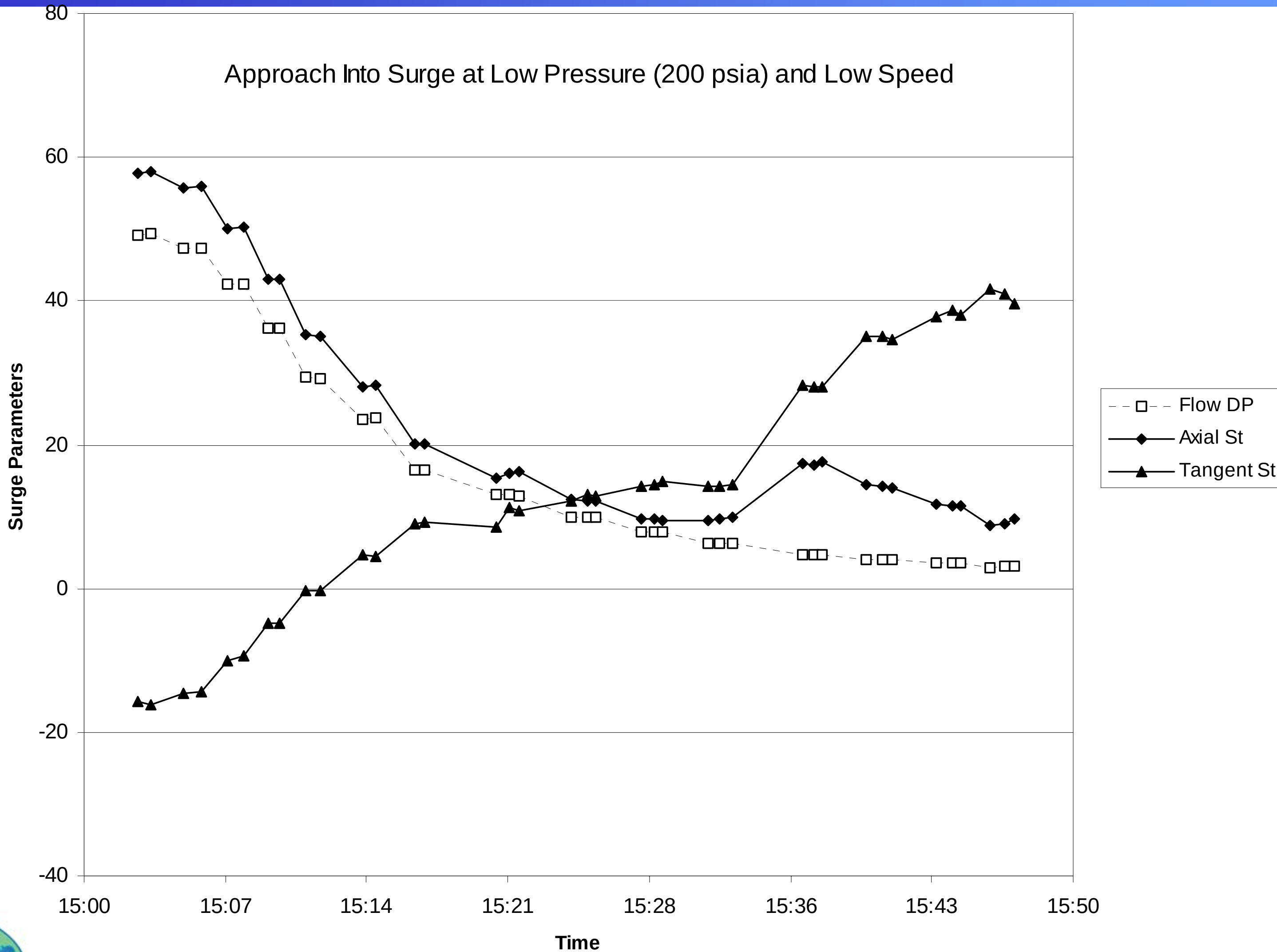
# Field Test B - Axial and Tangential Strain at Low Pressure & Low Speed



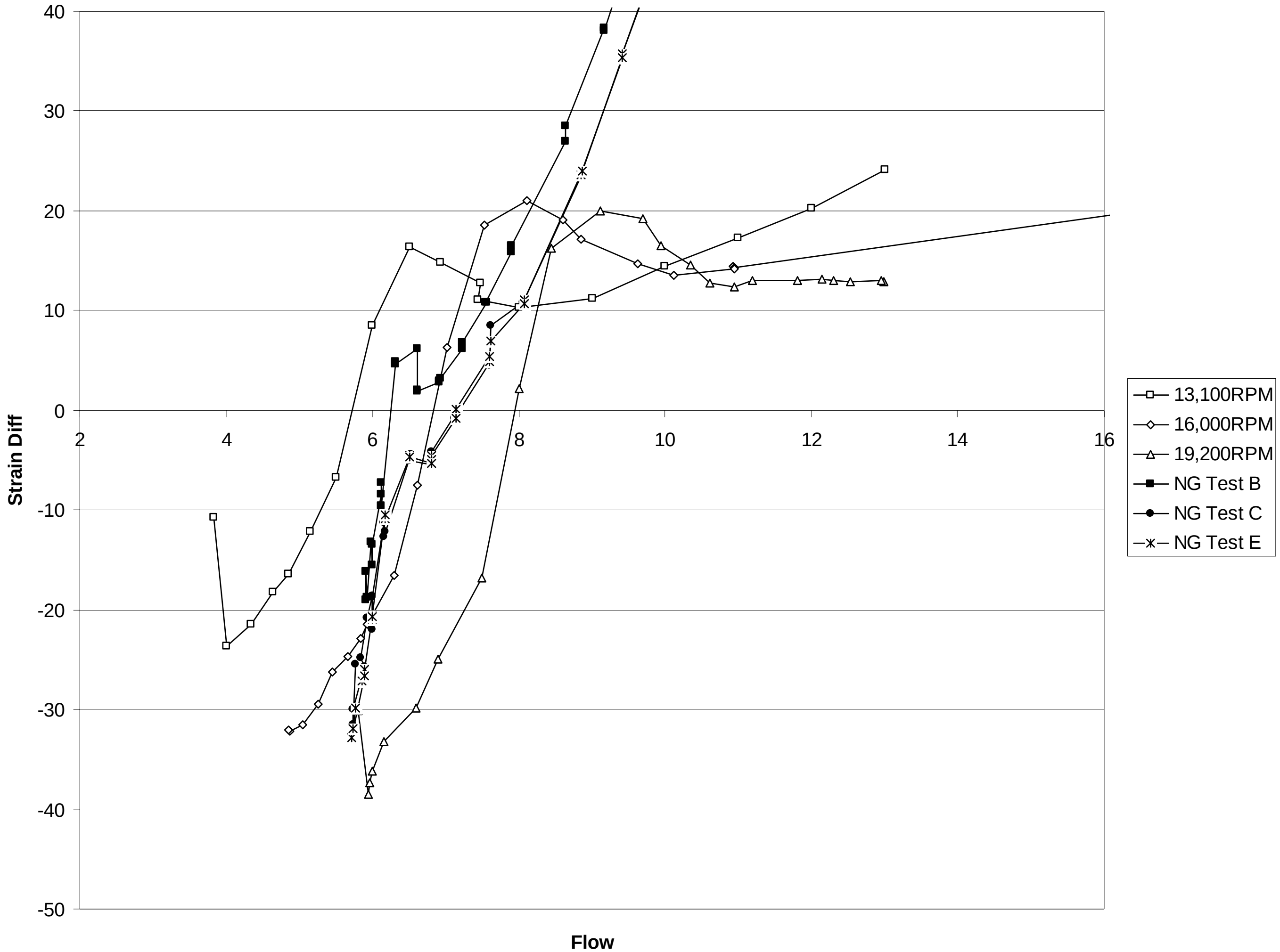
# Field Test C - Axial and Tangential Strain at Low Pressure & Low Speed



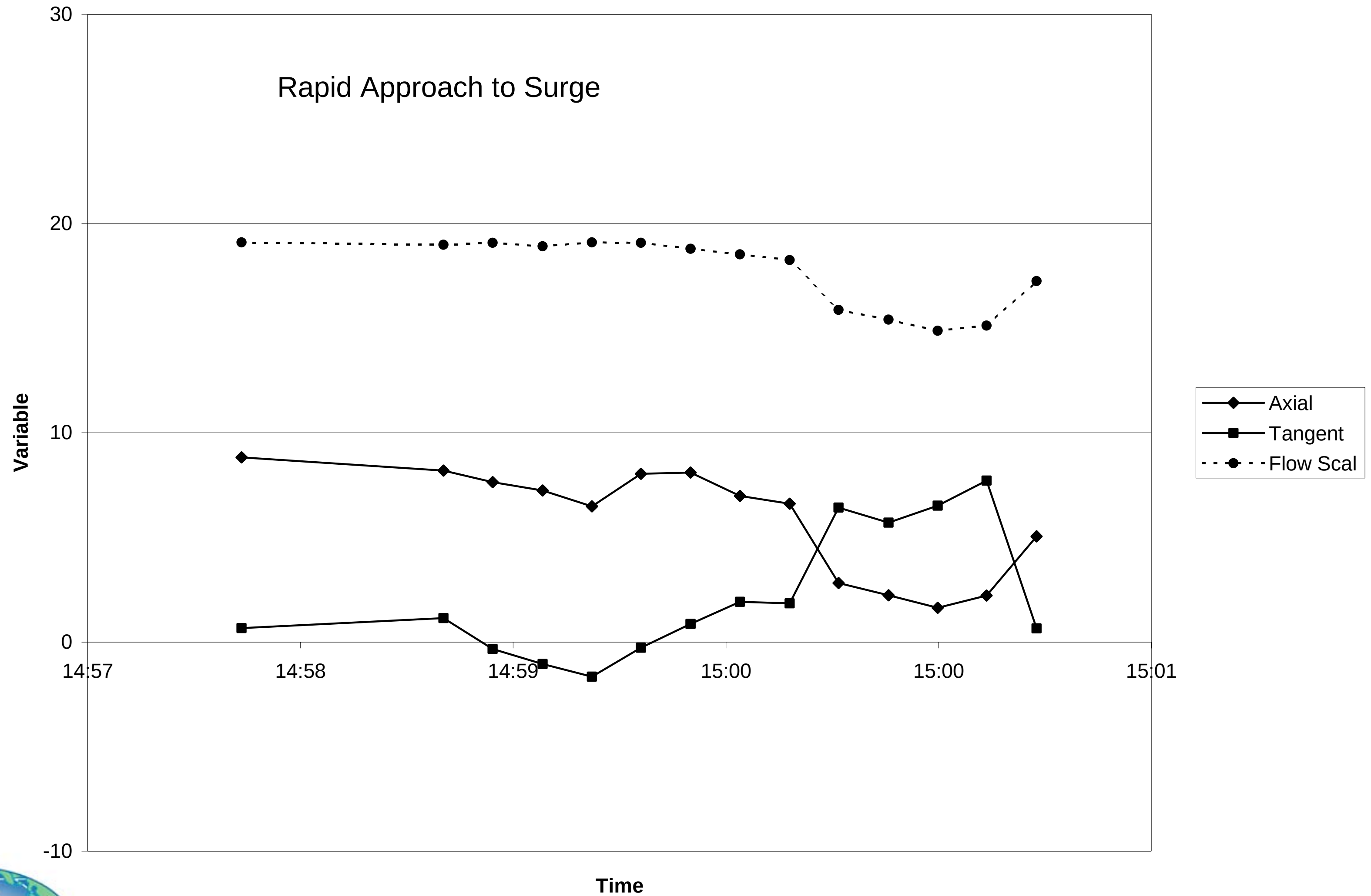
# Field Test E - Axial and Tangential Strain at Low Pressure & Low Speed



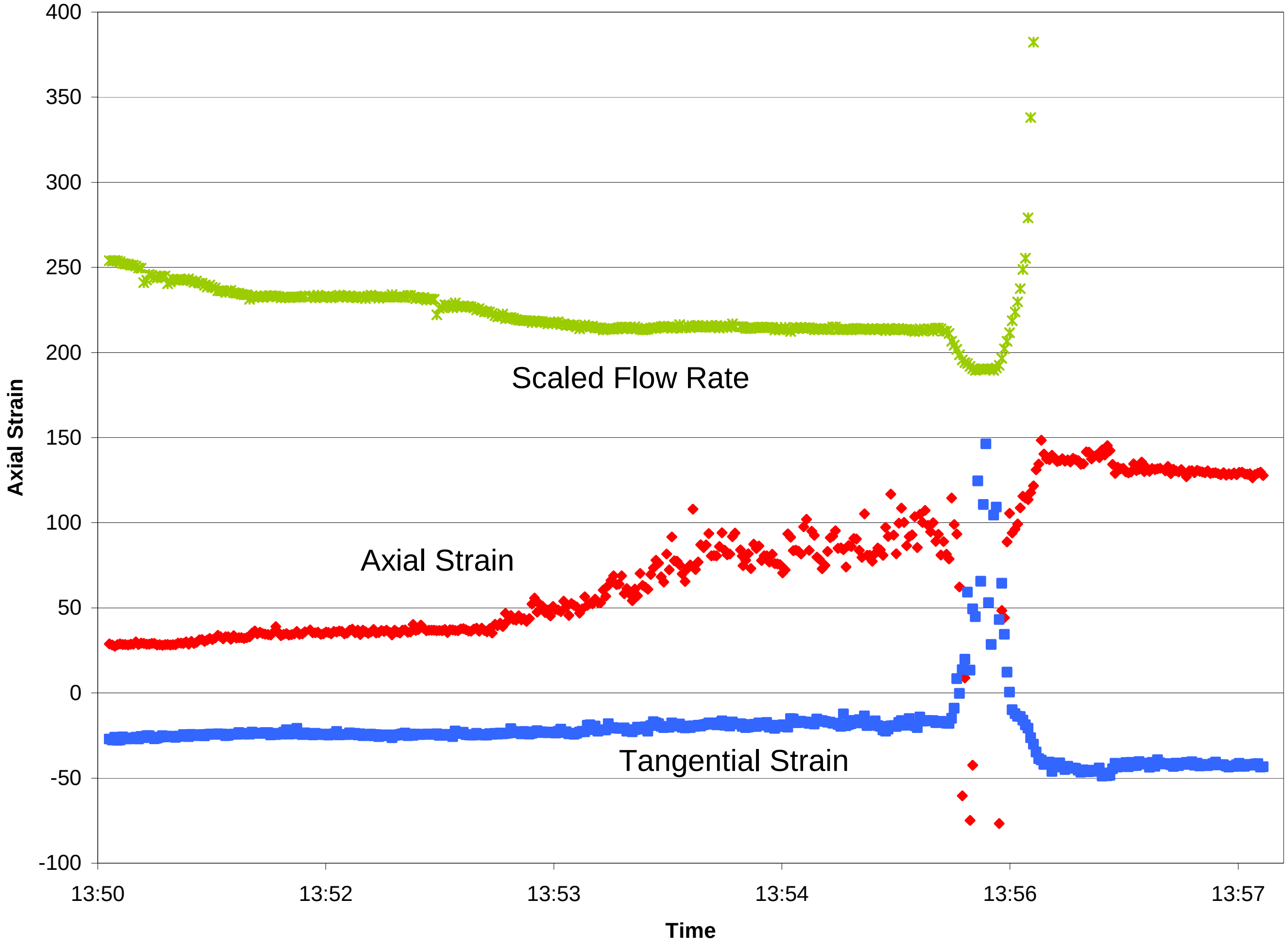
# Plot of Strain Difference as a Function of Nominal Flow for Lab and Field Tests



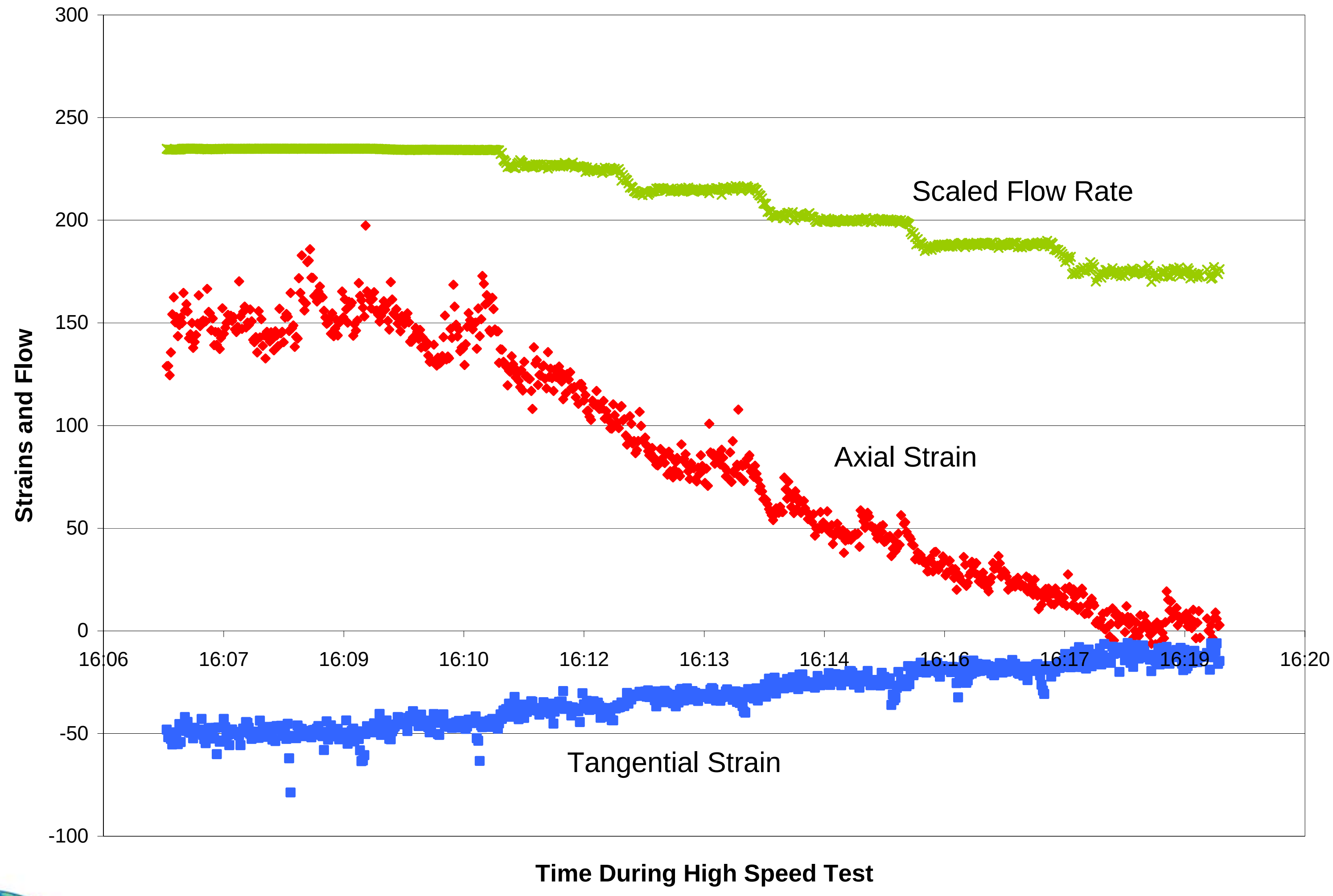
# Axial and Tangential Strain Changes During a Rapid Approach to Surge



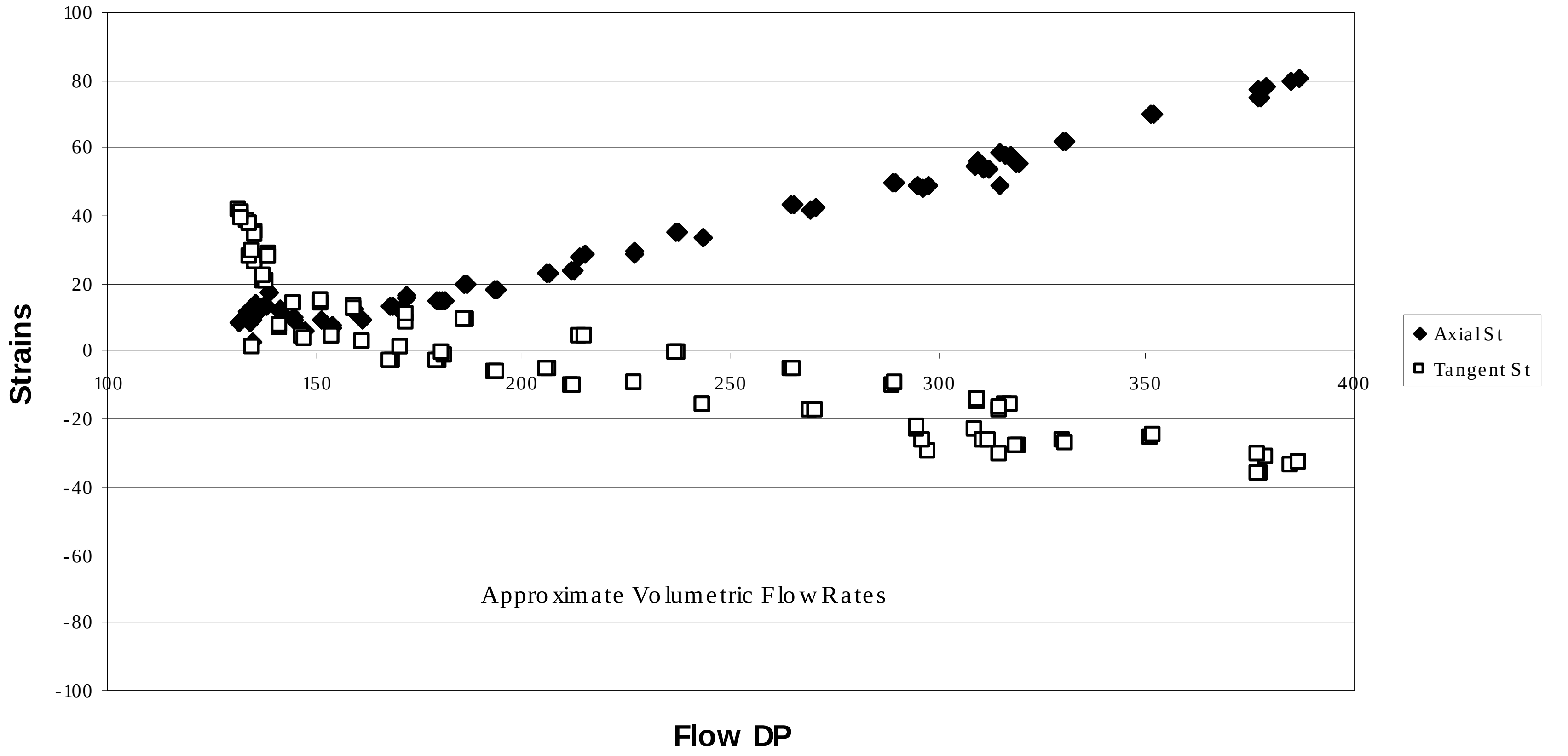
# Axial and Tangential Strain During a Moderate Pressure Approach to Surge



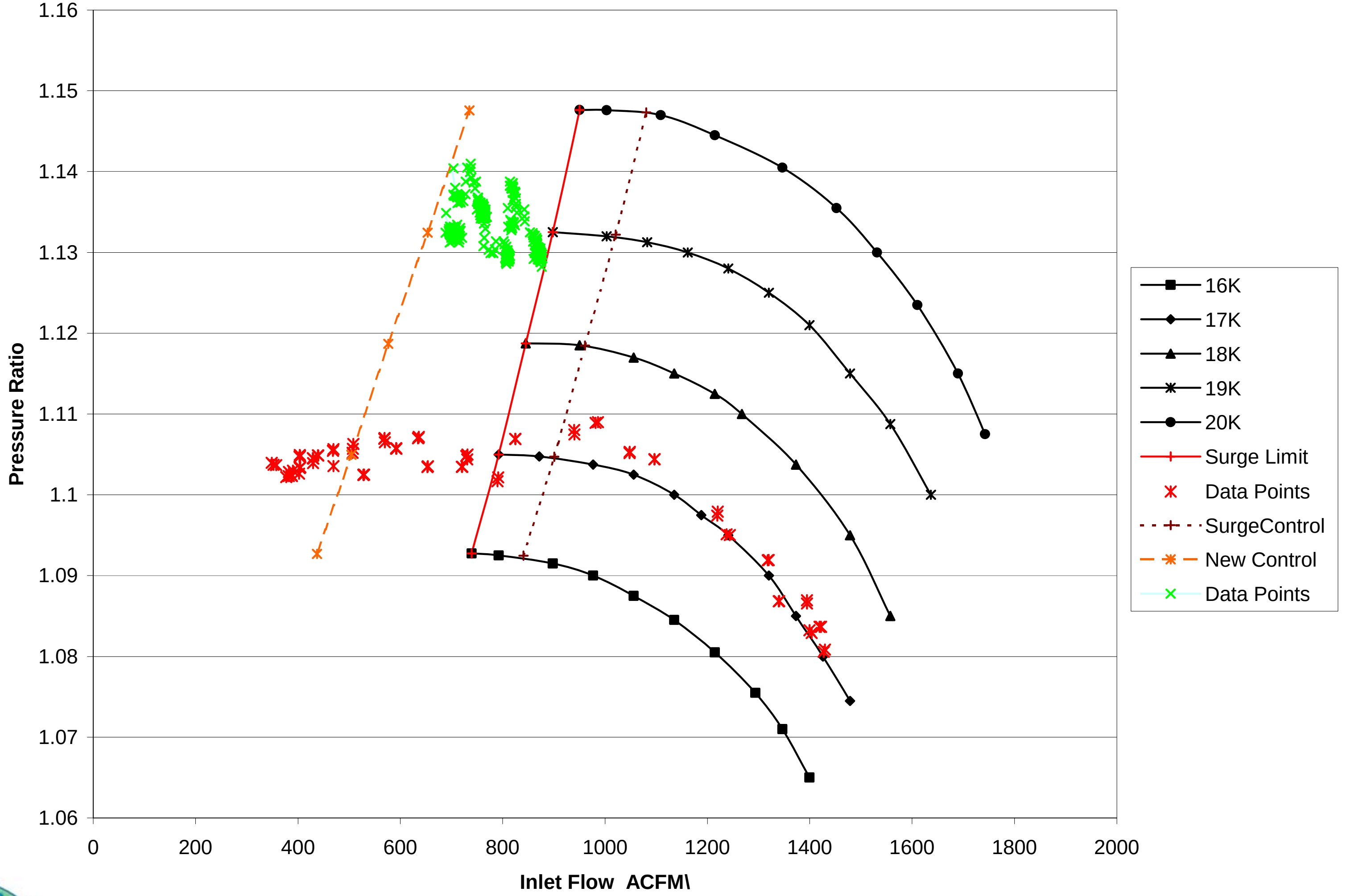
# Axial and Tangential Strain During a High Pressure High Speed Approach to Surge



# Trends is Strain as the Field Compressor Approached Surge



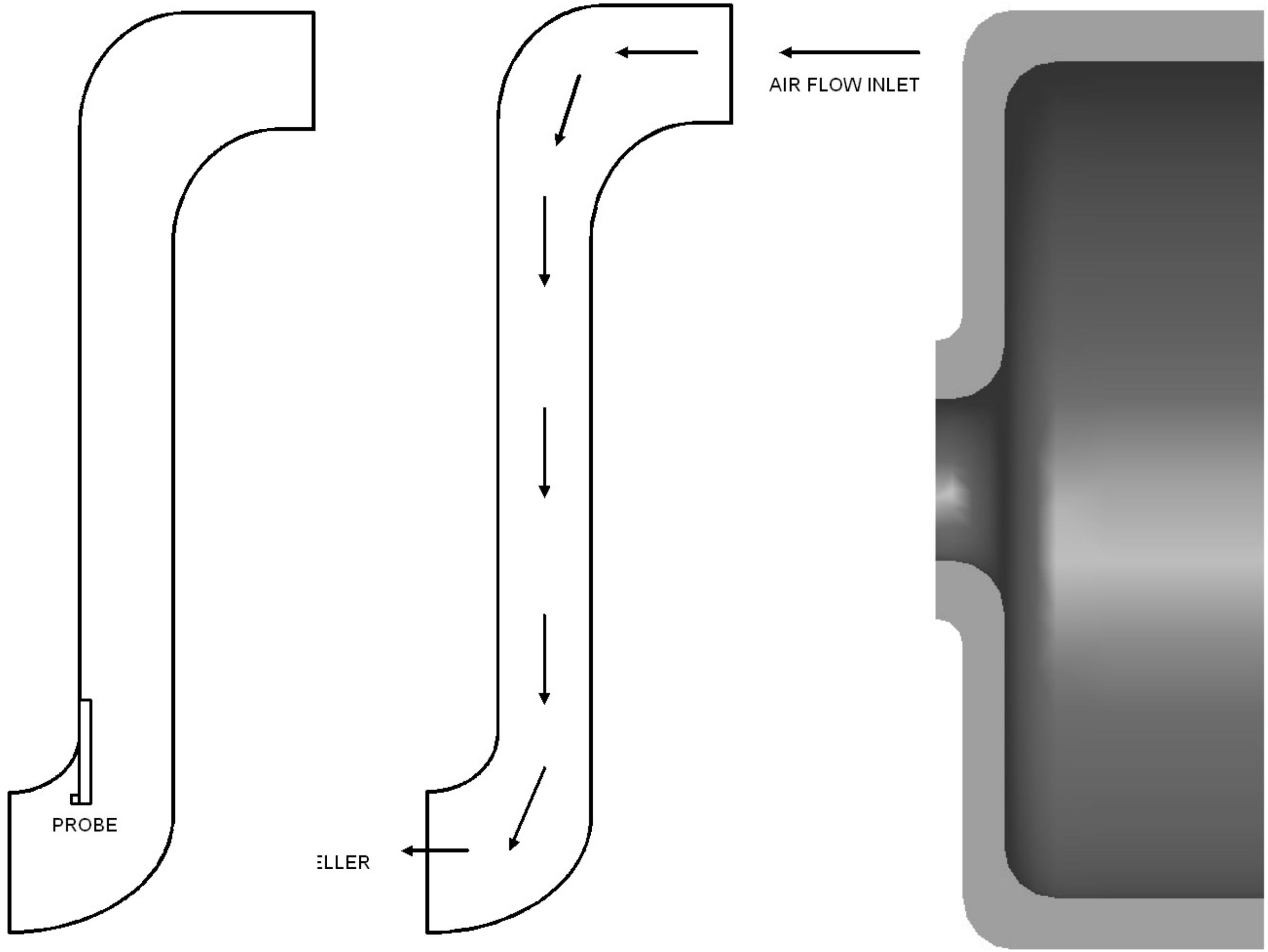
# Field Compressor Performance Map with Direct Surge Control



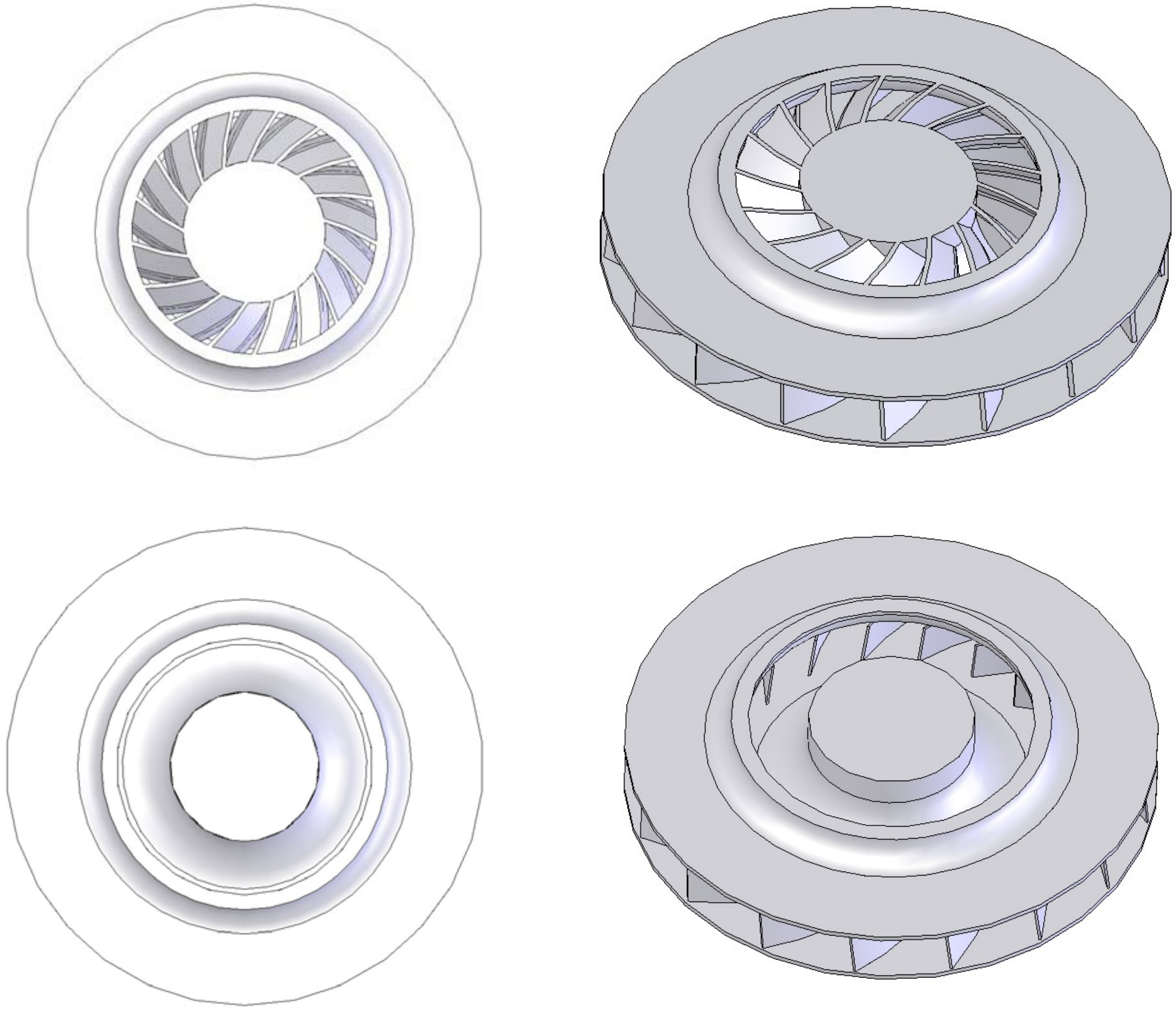
# CFD Modeling of Impeller Inlet Flows

- To determine if CFD analysis can be used to predict re-circulation zones.
- To explain the differences between 2D and 3D impeller results.
- Undertaken as a result of improved modeling capability and better understanding of geometric and operational flow effects on re-circulation.

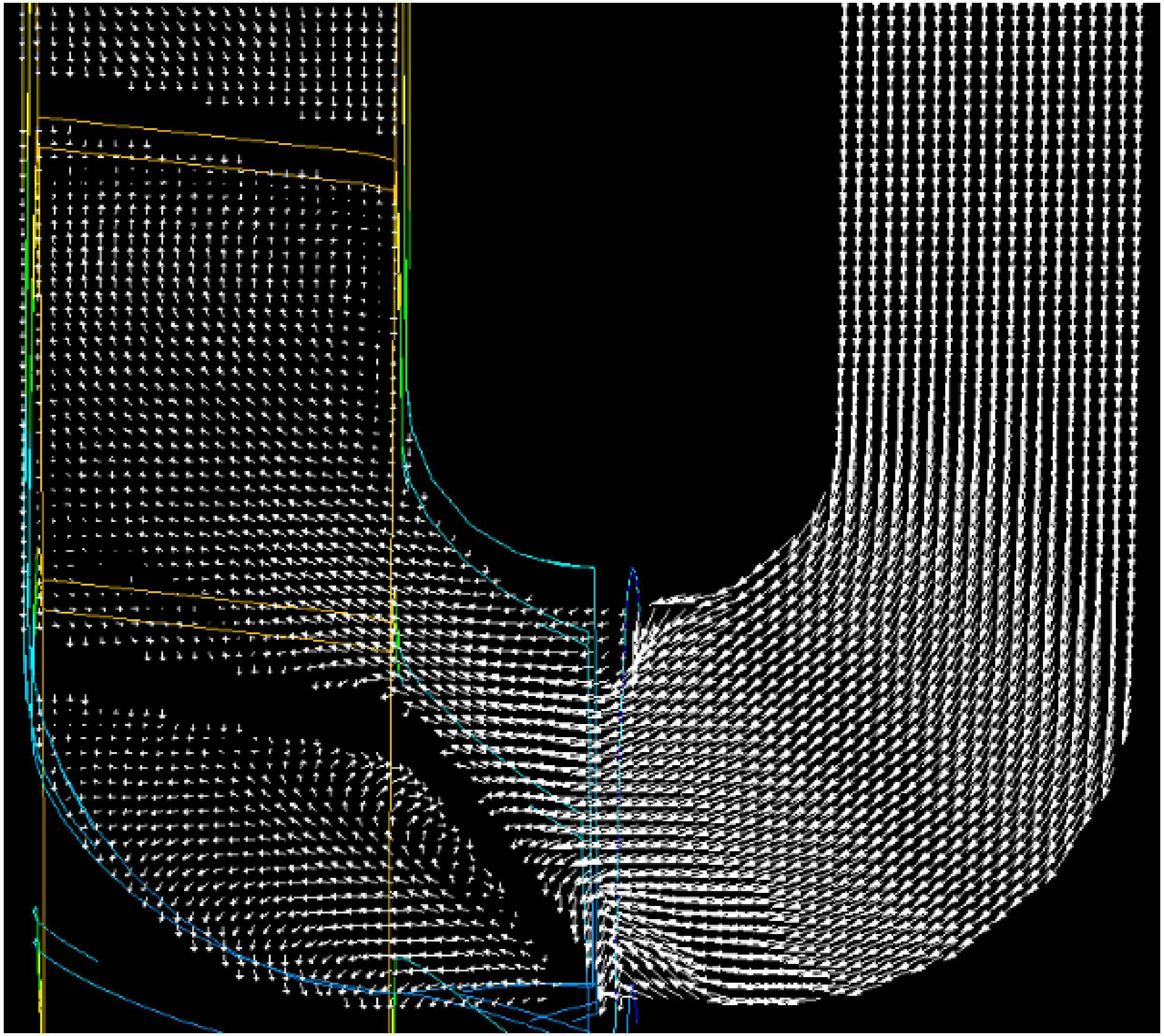
# Cross-Section of the Modeled Impeller Inlet Flow Path



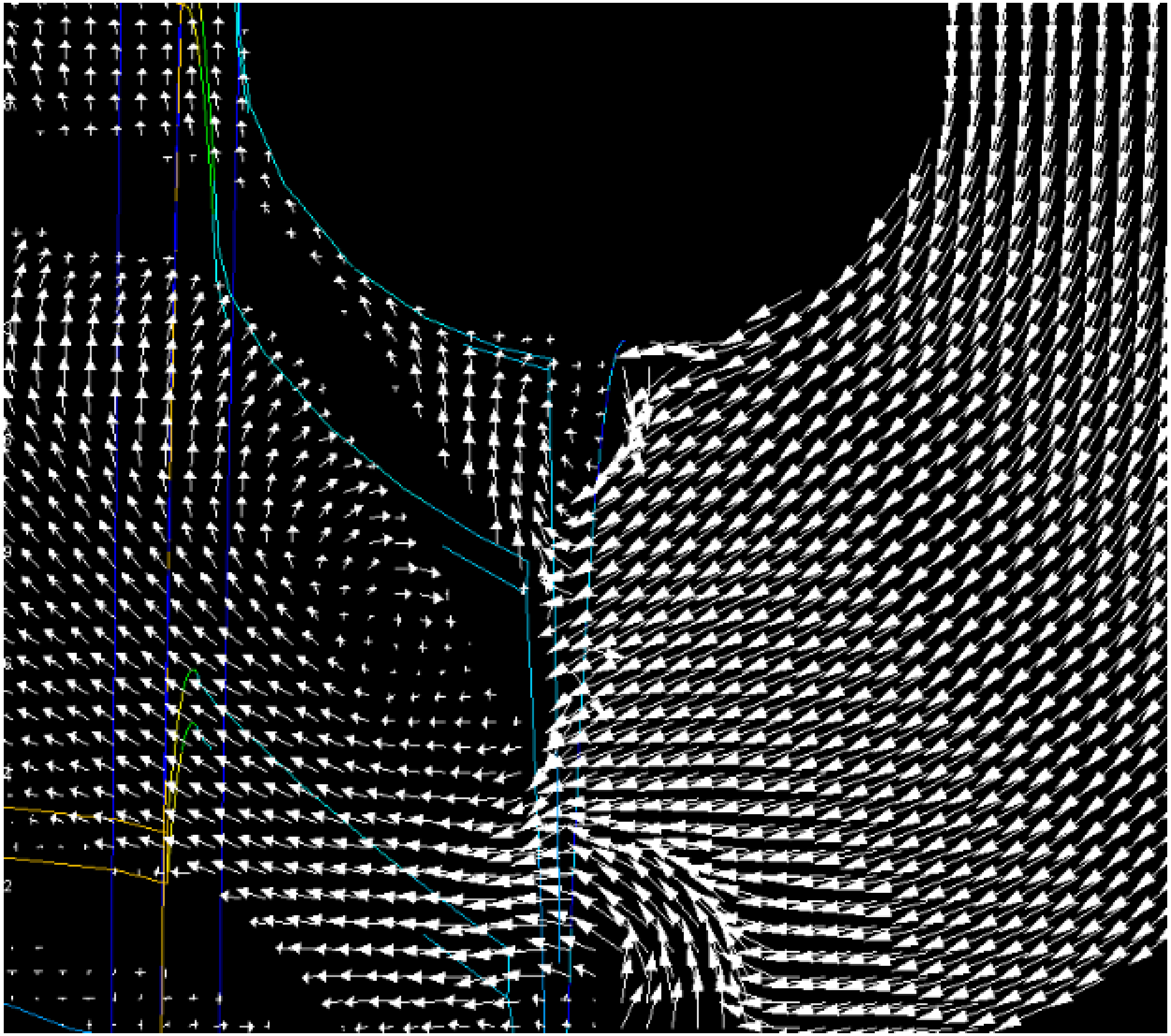
# CFD Models of 3D and 2D Impellers



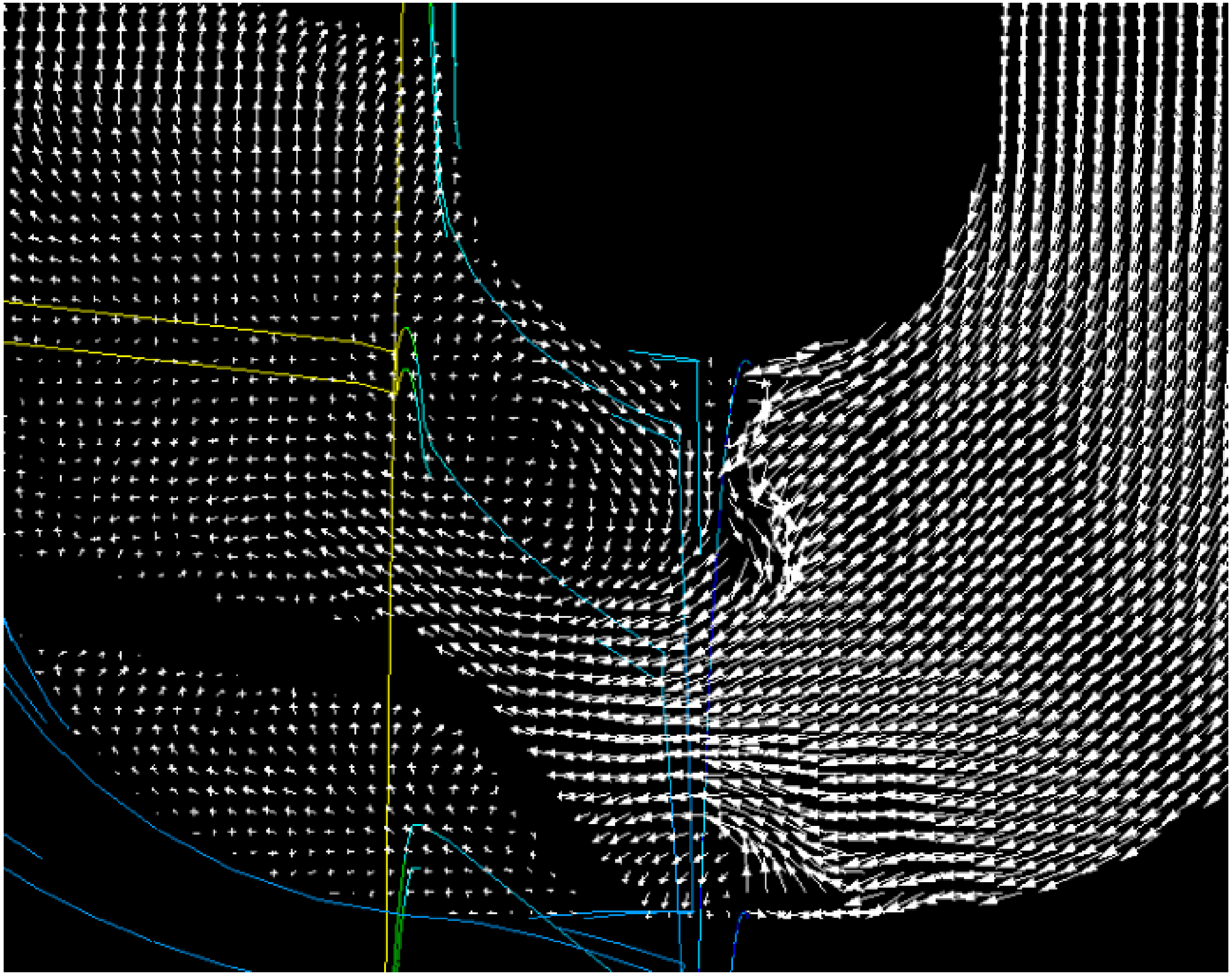
# CFD Results at Design Flow (1037 ACFM)



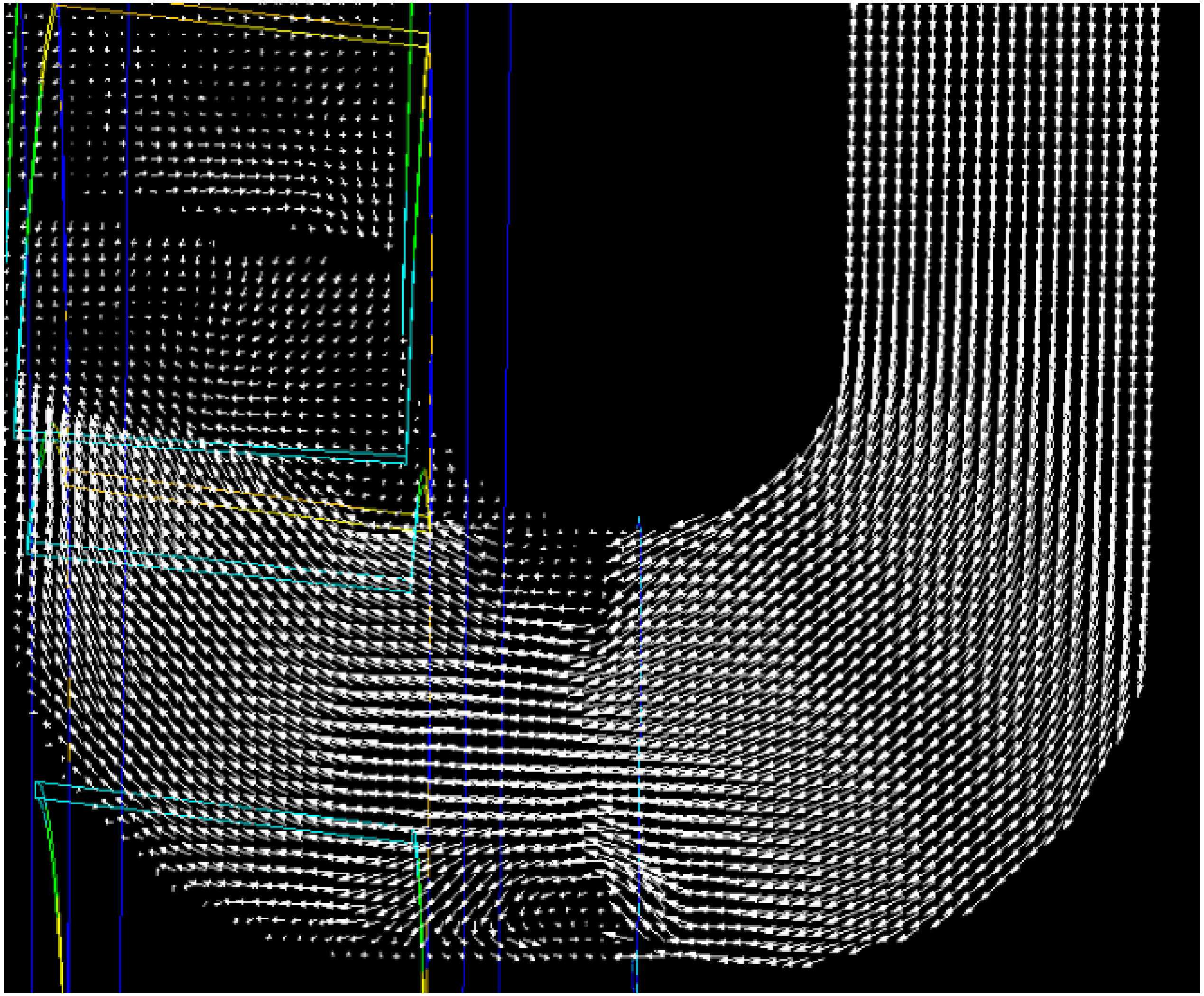
# CFD Results at Surge Line (685 ACFM)



# CFD Results at Near Actual Surge



# CFD Results for 2D Impeller at Low Flow



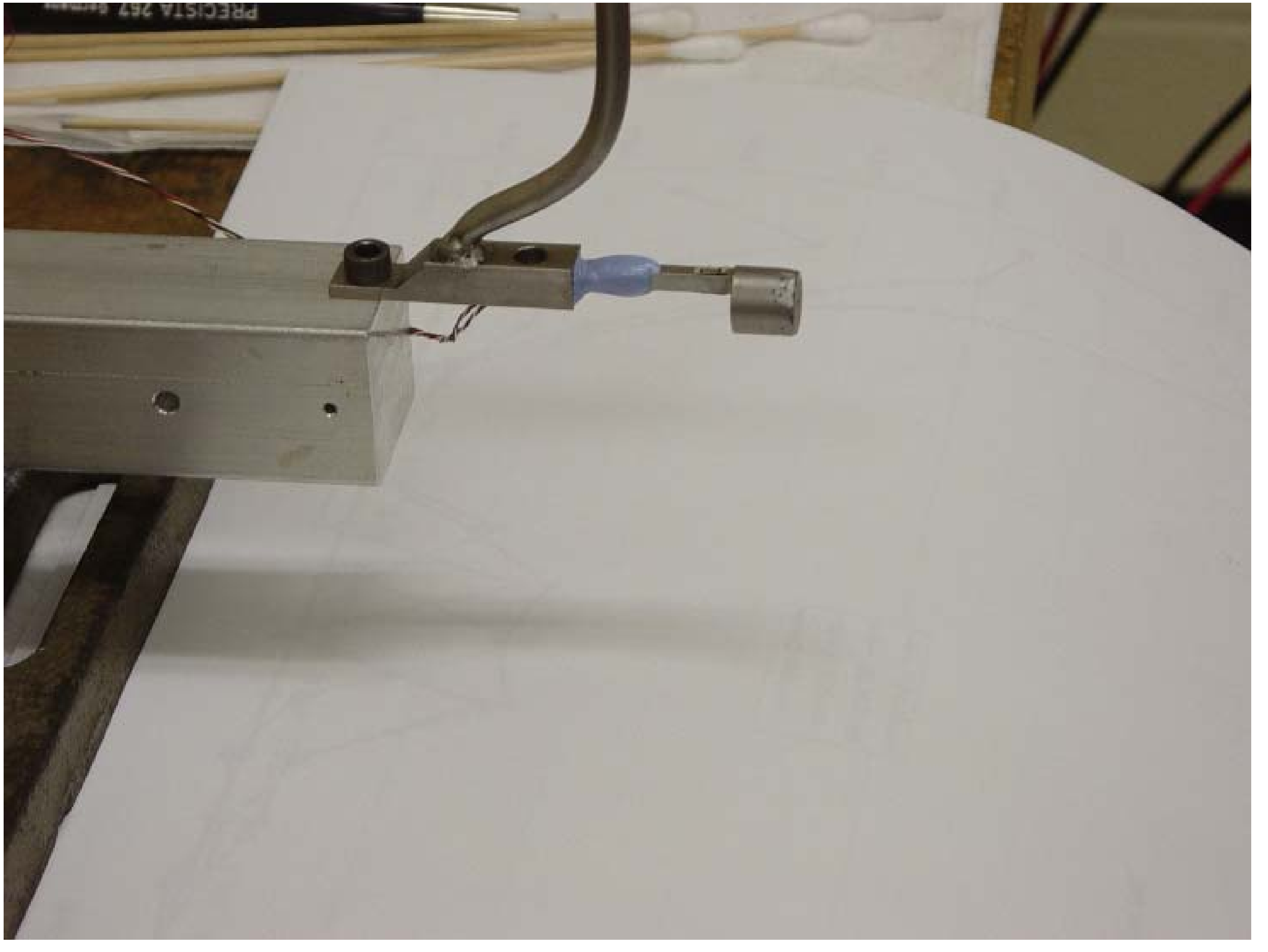
# Steps for Implementation of Direct Surge Control - Part 1

1. Determine that the compressor is a modern, single-stage machine with a 3D impeller.
2. Calculate the flow velocity and gas density ranges at the impeller inlet (area required).
3. Size the drag body (start of an iteration).
4. Calculate the forces acting on the drag body for the full range of flows. ($C_D$ = 0.5)
5. Determine the probe's bending beam width (square) and length for strength and sensitivity.

# Steps for Implementation of Direct Surge Control - Part 2

6. Calculate the strain expected from gauges due to maximum and near surge flows.
7. Calculate the mechanical natural and vortex shedding frequencies. Check that these do not coincide with compressor or other frequencies.
8. Design the probe holder to secure the probe in the correct location at the impeller inlet. Check the location relative to the expected re-circulation using a CFD analysis.
9. Check that the final design is properly sized, rugged (strong), sensitive, and vibration free. If it is not, return to Step 3 to adjust variables.

# A Drag Probe Resulting from Design Steps and Ready for Installation



# Steps for Implementation of Direct Surge Control - Part 3

10. Arrange for the signal wires to pass through internal dividers, in conduits, and a pressure fitting to the outside of the compressor case.
11. Connect the probe wires to an amplifier and a surge controller to monitor axial and tangential strain signals, filter (avg.), and process the strain indications of approaching surge.
12. Tune the balance, gain, filter, and algorithms to control the compressor to minimize recycle flow and achieve stable, wider, and efficient operation.

# The Surge Controller should;

- Accommodate two half bridge amplifiers for the strain signals with ±5 volt outputs.
- Sample data at 80 to 240 Hz to follow flow changes but not high frequency noise or disturbances.
- Satisfy Class I, Div. 2, Group D in a NEMA panel.
- Monitor compressor speed, pressure, temperature, & flow as a convenience for display and recording.
- Filter by short averaging and process the strain signals through a selected algorithm such as the difference of axial and tangential strain and provide an output when the signal drops below a set limit.

# Conclusions

- Surge is a potentially damaging flow instability that limits the low-flow operation of centrifugal compressors and is usually avoided by wasteful and inefficient recycling of flow.
- Early GMRC research identified flow recirculation along the outer wall of a compressor inlet as a surge precursor and a potential control signal that can be sensed with a drag type probe.
- A step-by-step design procedure for direct surge control drag probes and controllers is defined by this research and given in the report.

# Conclusions - continued a

- Surge probes designed per the procedures and fabricated per specifications need to be checked functionally but not calibrated or flow tested.
- Test results show that for sensitive near surge detection, with the current methods the impellers must be a modern 3D design.
- Flow changes along the outer wall of a centrifugal impeller inlet do produce re-circulating flows, which cause axial and tangential strain changes on a drag probe that indicate the approach of surge.

# Conclusions – continued b

- A control algorithm based on comparing the difference between the axial and tangential strains is less sensitive in installation details and can be used as a surge control method.
- Operational tests show an increase in low flow range of up to 25 percent for compressors with direct surge control. A potential savings of 10 to 24 MSCF or $50 to $120 per hour of operation is expected.  The possible industry wide saving is $50 to $85 million per year.
- CFD modeling can be used to check the location of a direct surge control probe in the re-circulation.

# Demonstration and Commercialization of Direct Surge Control

- The direct surge control system is successful as a prototype but needs to be demonstrated as a commercial product in a pipeline compressor.
- SwRI, along with the GMRC advisors, will identify and interview a number of potential application contractors and will help to select one.
- The interest of all parties, DOE, Siemens Energy & Automation, Solar Turbines, others, and particularly the user companies, will be considered.
- A demonstration project led by an application contractor will install a system in a member's pipeline compressor & operate it for all to see.

# Tasks in the Demonstration and Commercialization Project

- Task A. Identify and select an application contractor or contractor alliance.
- Task B. Transfer the technology for design and installation of direct surge probes and controller interfaces to the application contactor.
- Task C. Conduct a field demonstration of the commercial direct surge control system led by the contractor with oversight from SwRI & GMRC.

# Companies to Consider as Potential Application Contractors

- Demag Delaval – A compressor division of Siemens.
- Petrotech Inc. – An experienced control system supplier.
- Alotronic - An experienced control system supplier.
- Cooper Compressor – A manufacturer of integral geared compressors.
- Solar Turbines – A manufacturer of pipeline compressors.
- Metrix – An instrument manufacturer.
- Compressor Controls Corp. – A controls supplier.
- Rosemount – An instrument company.
- Many Others

# SwRI's Actions at the Start of the Project

- Contact each company to discuss the technology and needs and to determine who is interested
- With the oversight committee, develop a selection criteria and what we need from the contractor.
- Request a proposal from the interested parties.
- Evaluate the proposal and with industry select one.
- Start the transfer of technology to the contractor.
- Plan for and monitor the demonstration test.
- Report to the GMRC at all stages in the project and on the final report.