Deep Throttle Turbopump Technology Testing

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Deep Throttle Turbopump Technology Testing

- Motivation and objectives
- Test article
- Test facility and setup
- Test procedures
- Test data results and discussion
- Summary and conclusions

Deep Throttle Turbopump Technology Testing

NRA history

- Work funded as part of NRA8-21 cycle 2 RBCC Turbopump Risk Reduction
- Input submitted April 1999 → task funded May 2001
  - $1.3M contract, planned term: 19.5 months
  - Expenditures: $440K; contract cancelled 1/02: lack of funds

Objectives

- Enhance and demonstrate critical technologies in support of planned RBCC flight test program
- Obtain knowledge of wide flow range as it is applicable to liquid rocket engine turbopumps operating over extreme throttle ranges

NASA partner acknowledgments

- Mr. Robert Garcia and Dr. Dan Dorney of MSFC

Deep Throttle Turbopump Technology Testing

Program Is Incrementally Staged

Wide Flow Range (WFR) Scope of Work

- Improve TP performance at off-design flows by designing and testing diffusers suitable for WFR operation
- Program divided into 4 major activities
  - Task 1: Diffuser flow test and database analysis
    - Collect vane-island diffuser data at off-design Q
    - Database analysis incomplete (not funded)
  - Task 2: Candidate WFR diffusers design & evaluation
    - Design, fabricate and test 2 WFR diffuser concepts
    - Design #1 complete, design #2 90% complete
    - Fabrication and testing incomplete (not funded)
  - Task 3: Design, fabricate and test WFR TP stage (not funded)
    - Inducer, impeller and diffuser matched for WFR operation
  - Task 4: RBCC top-level turbopump conceptual layout (not funded)
    - Incorporate knowledge gained to specific requirements

this talk

prior talk

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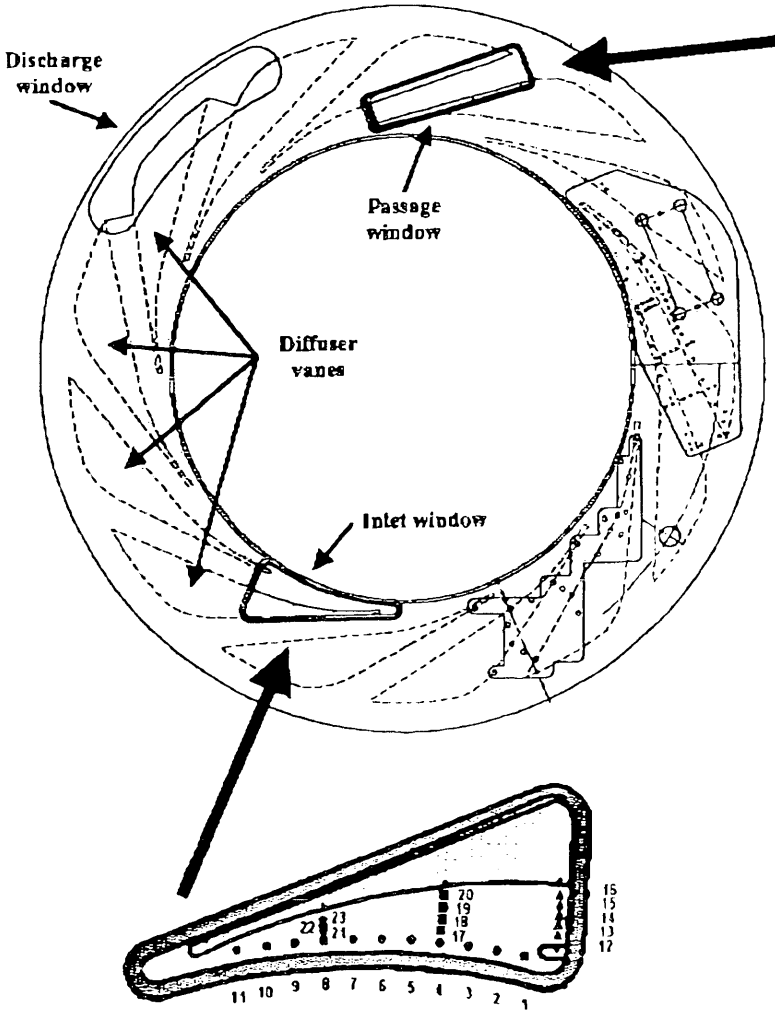

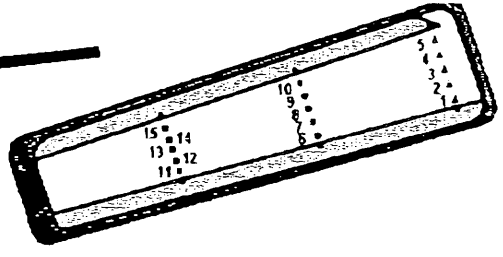

NEW DATA

Laser Velocimetry Database

Location	Flowrate as % of Qd	
	80	100
Impeller Discharge Window		
half-way plane between impeller OD & diffuser ID	2001	1996 & 2001
Diffuser Inlet Window		
arc	n/a	1996
plane A (throat)	1996	1996
plane B	n/a	1996
plane C	n/a	1996
Diffuser Passage Window		
inlet plane	1996	1996
mid-passage plane	1996	1996
discharge plane	1996	1996
Diffuser Discharge Window		
arc	n/a	n/a

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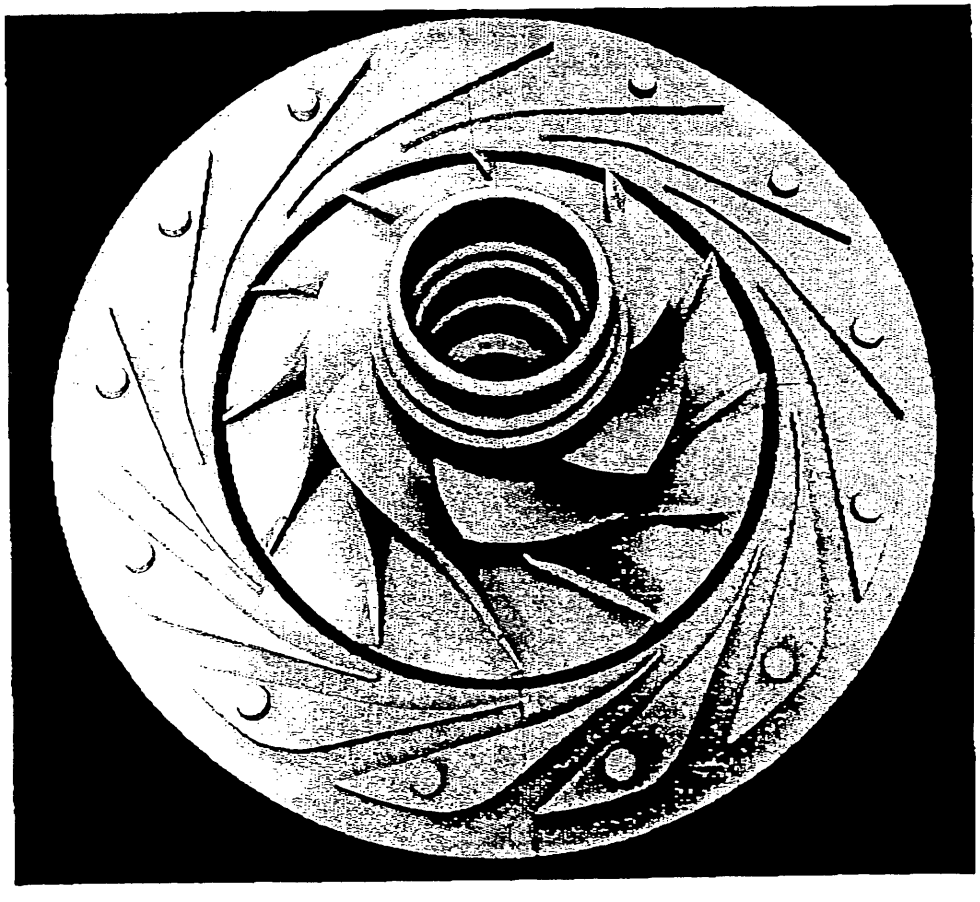

Number of impeller vanes	6 + 6
Impeller diameter (in)	9.045
Impeller B2 width (in)	0.574
Impeller tip speed (ft/s)	249.505
Impeller inlet design flow coefficient	0.144
Shaft speed (rpm)	6322
Flow rate (gpm)	1210
Number of diffuser vanes	13
Diffuser inner diameter (in)	9.355
Diffuser outer diameter (in)	14.703
Diffuser vane leading edge radius (in)	4.886
Diffuser vane discharge radius (in)	6.757
Diffuser throat width (in)	0.403
Diffuser discharge width (in)	0.601
Diffuser throat B3 (shroud to hub), (in)	0.466
Diffuser discharge depth B4 (shroud to hub), (in)	0.806
Diffuser constant flow area discharge diameter (in)	17.230

- Plastic models shown
- Impeller shroud removed

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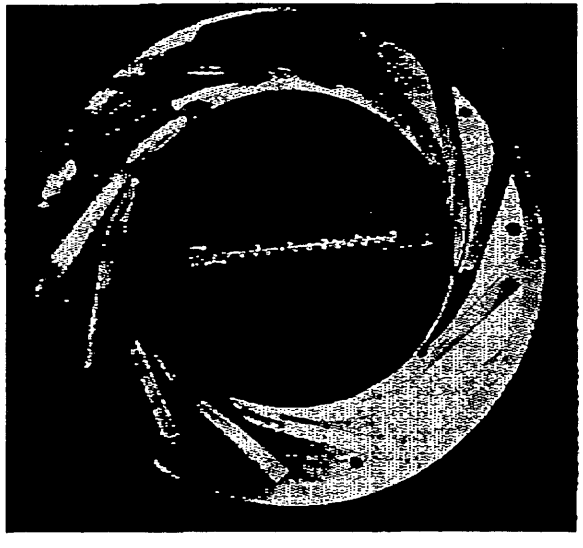
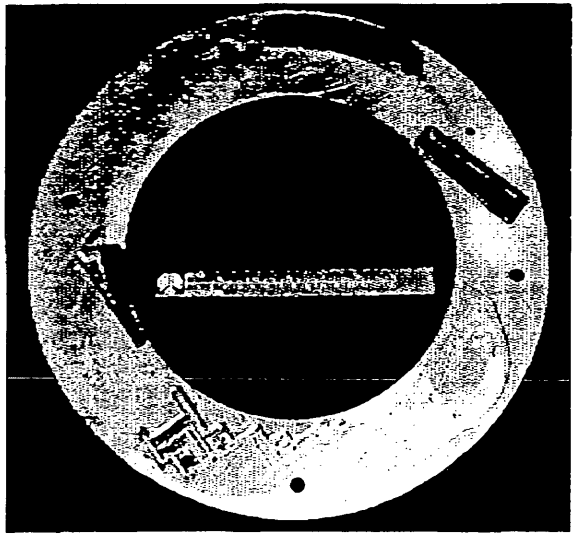
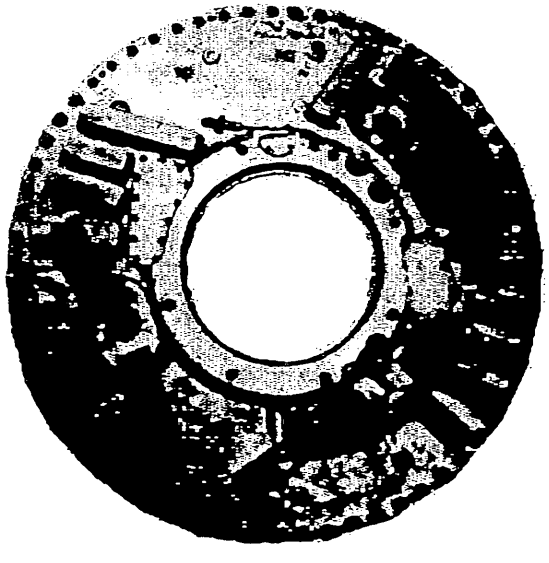
Assembly Provid[illegible] Impeller Discharge



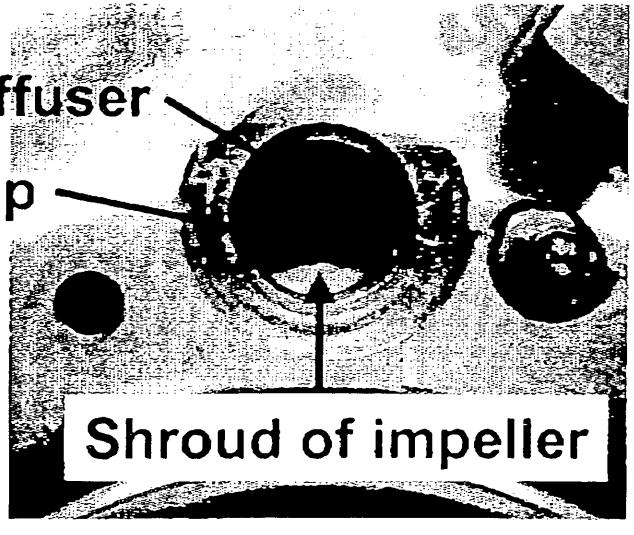




coverplate

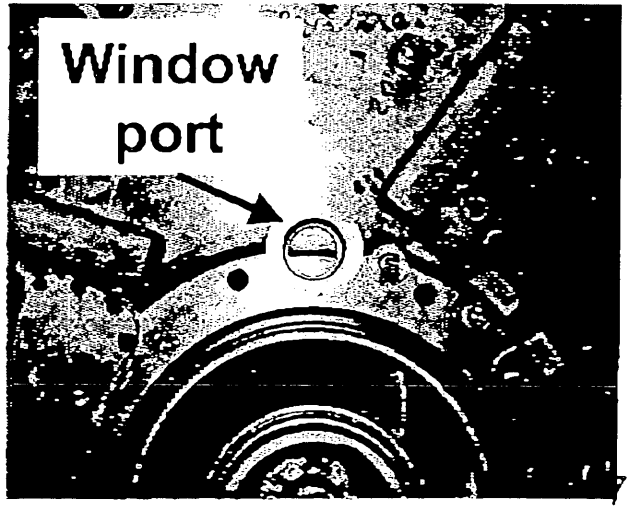
Shroud of diffuser

0.155" gap



Shroud of impeller

Window port



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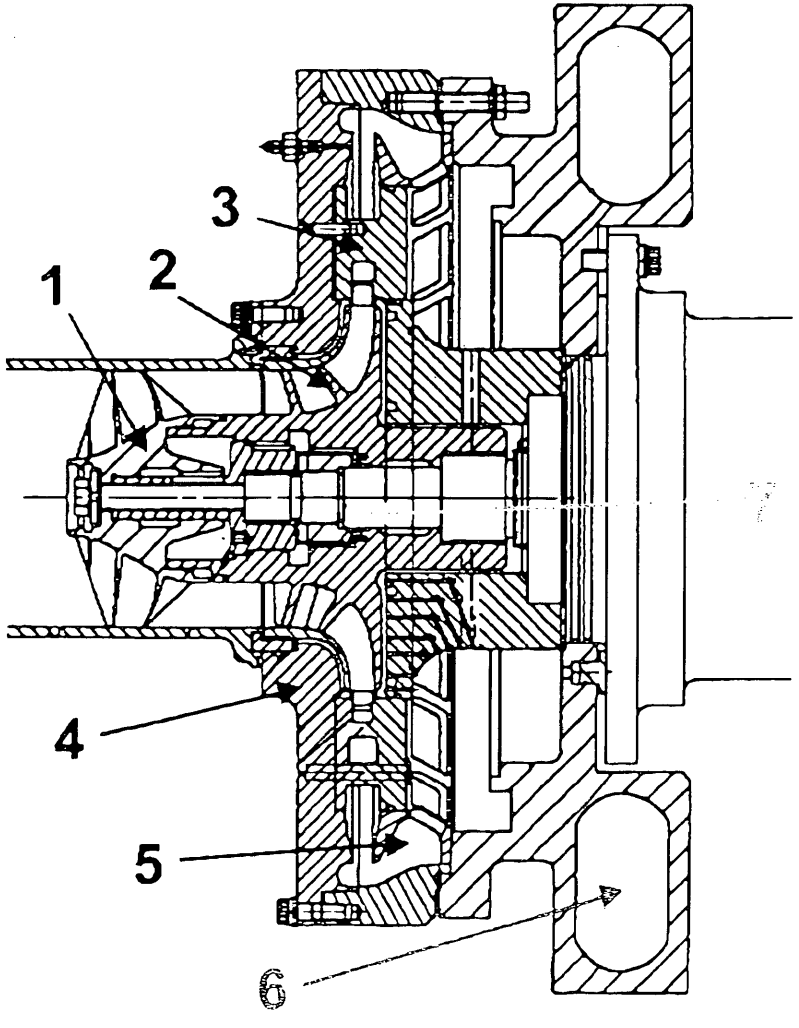
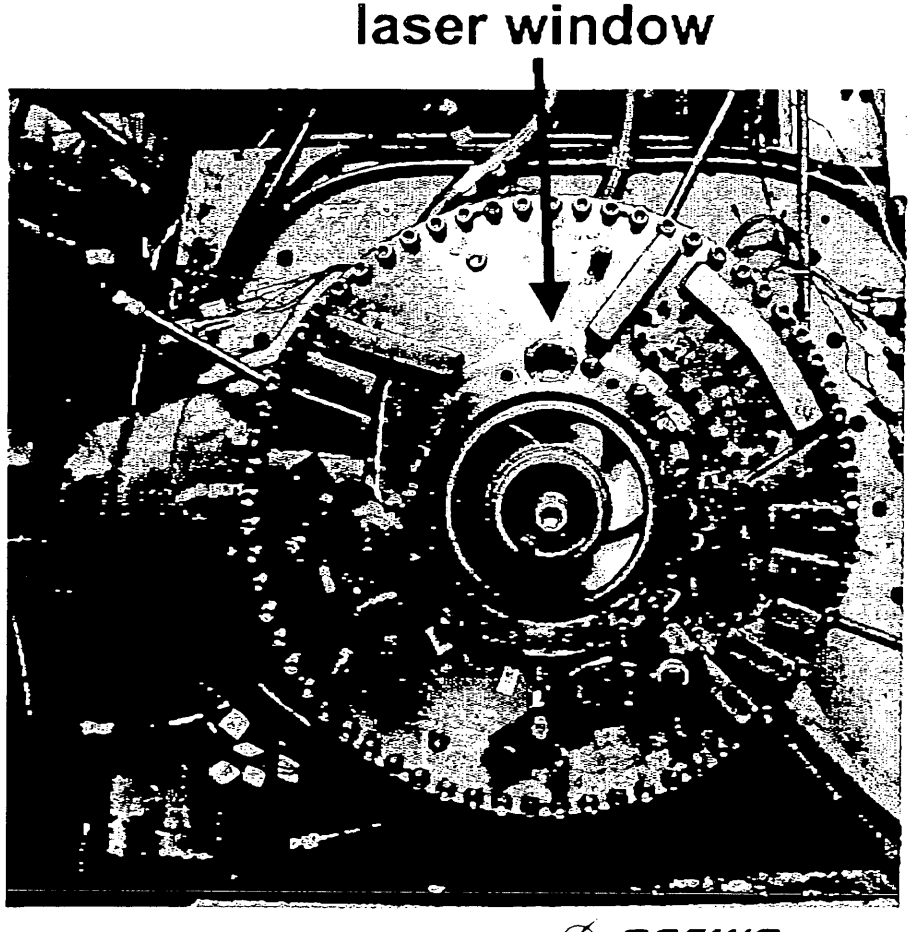
Major Components





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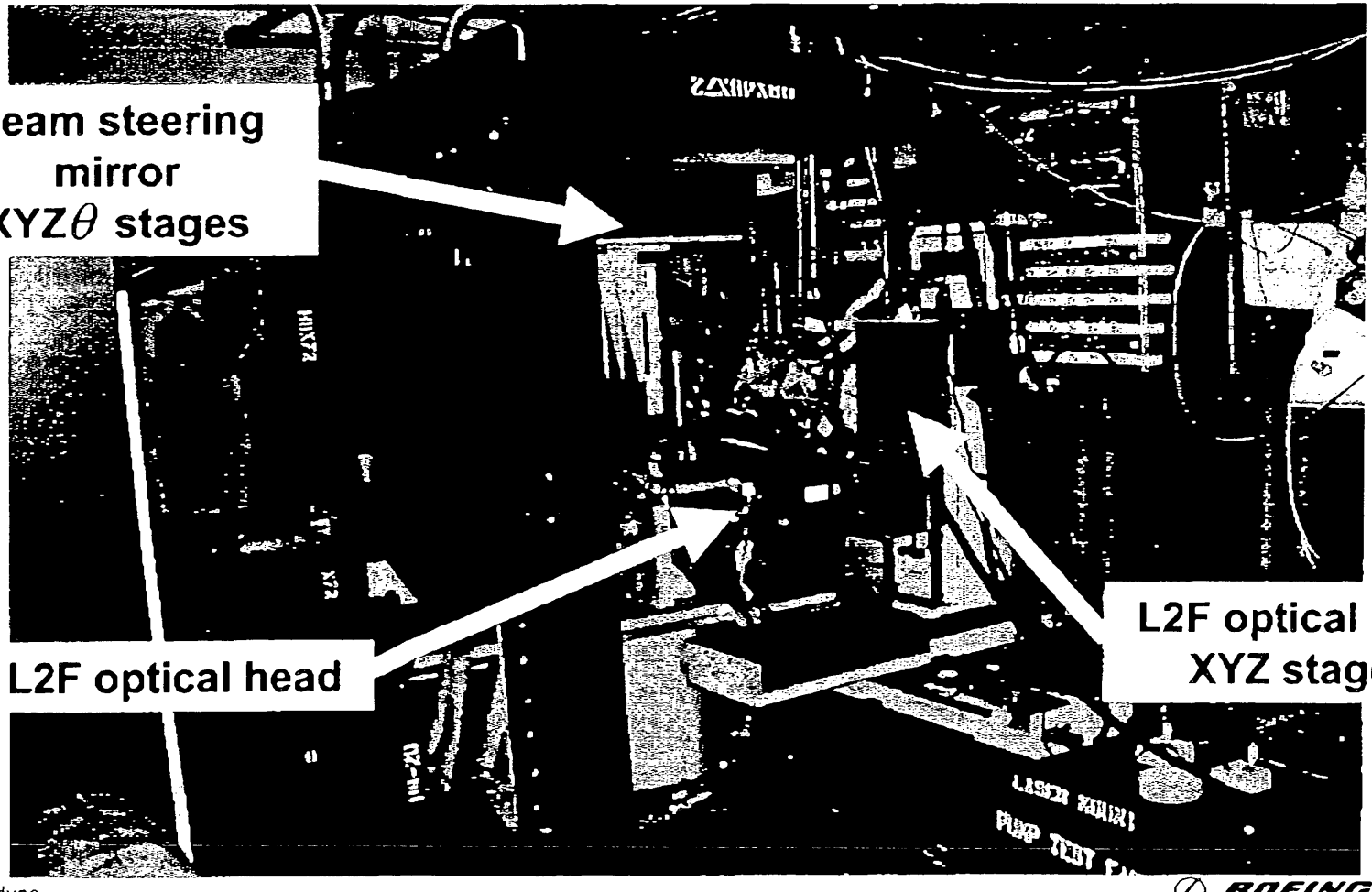
Turbine Drive Pump Features 7 Translation Systems



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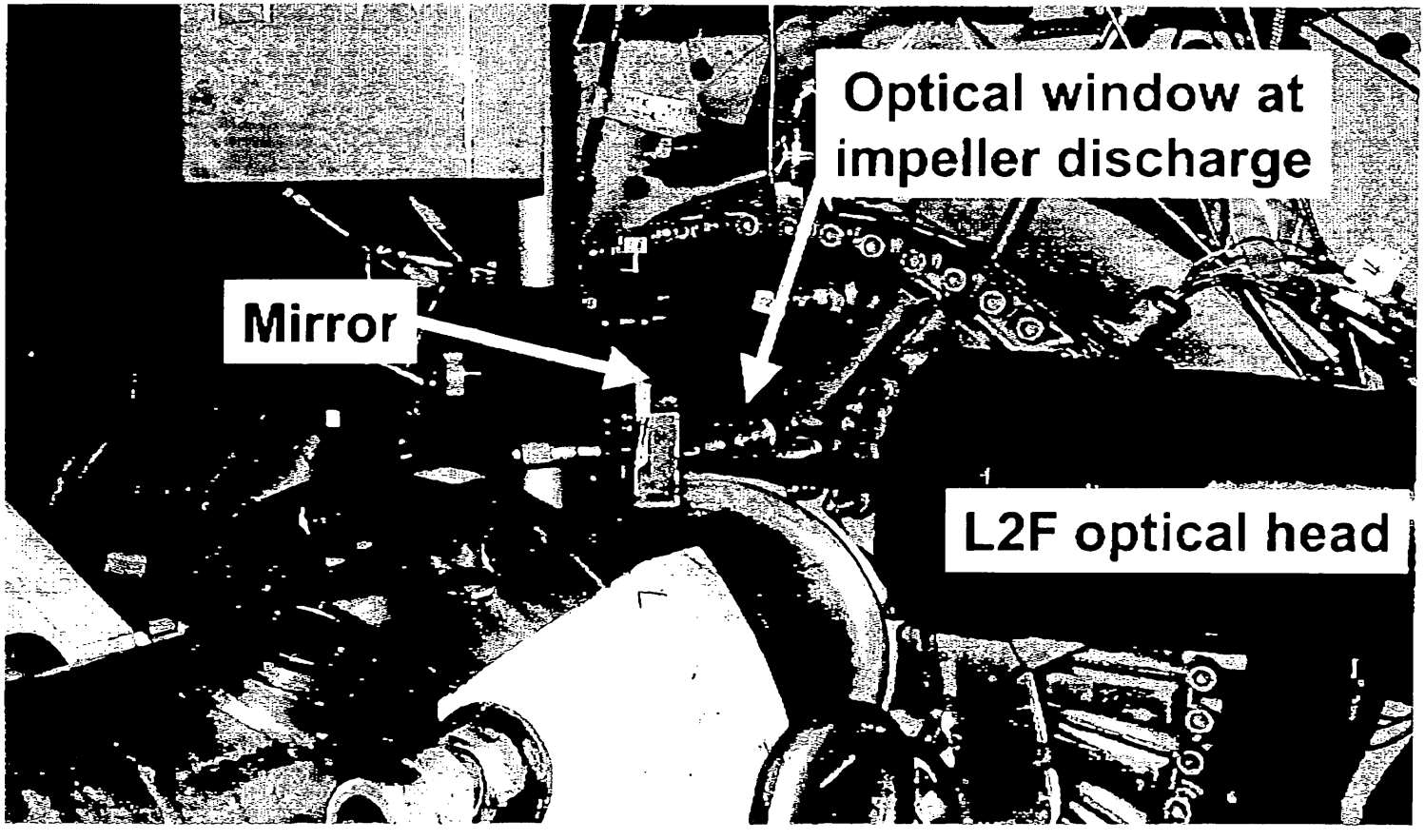

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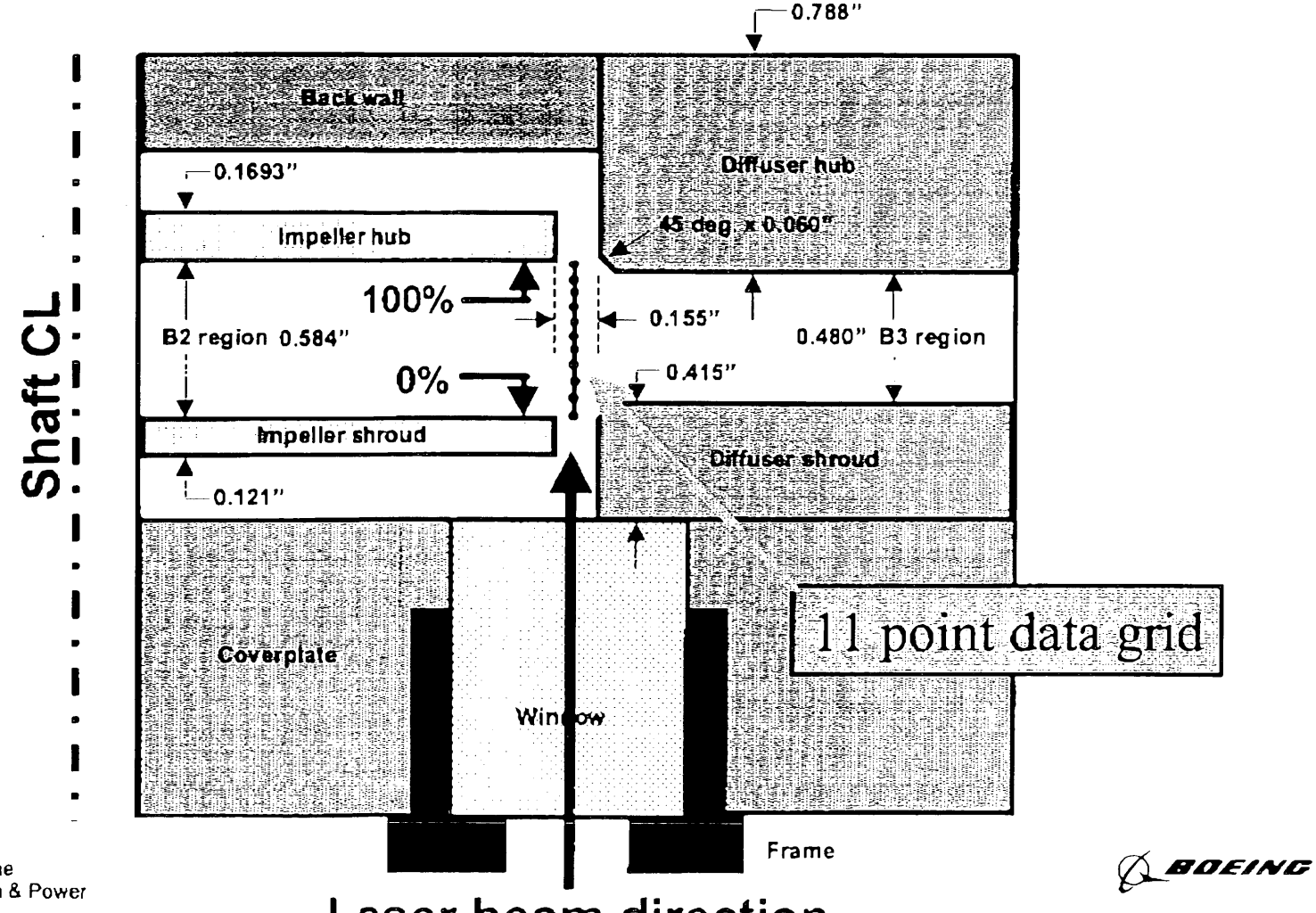

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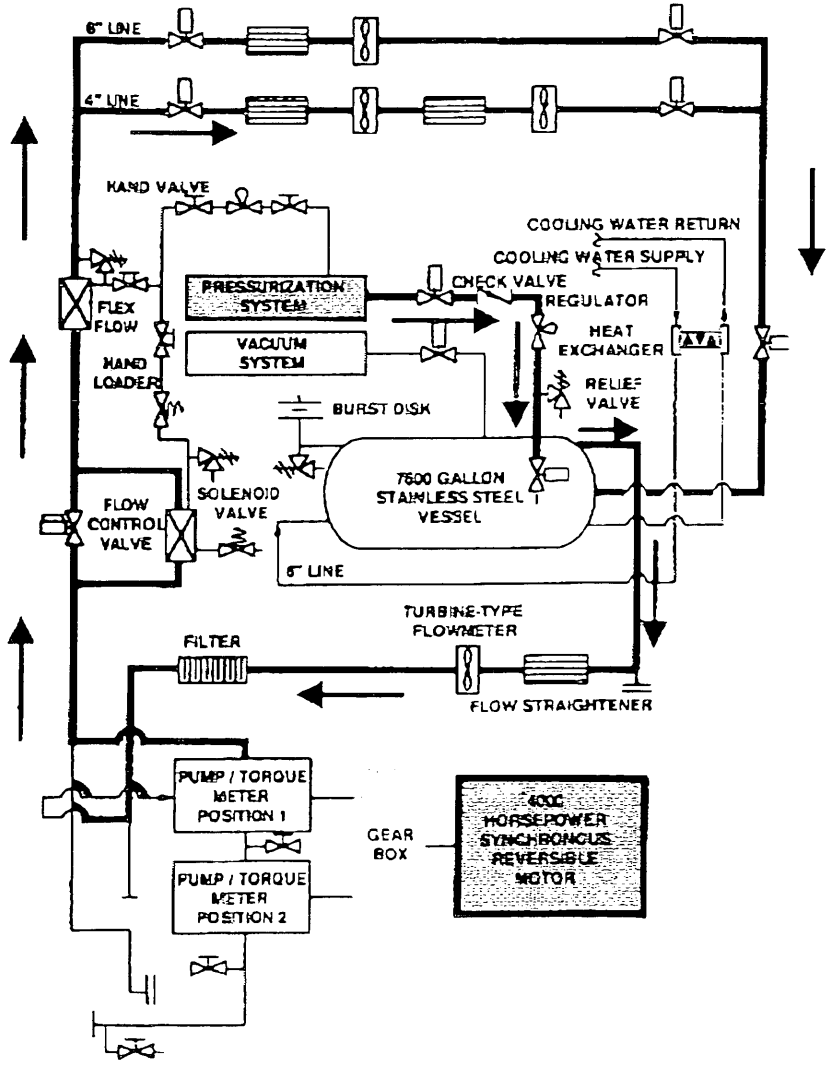

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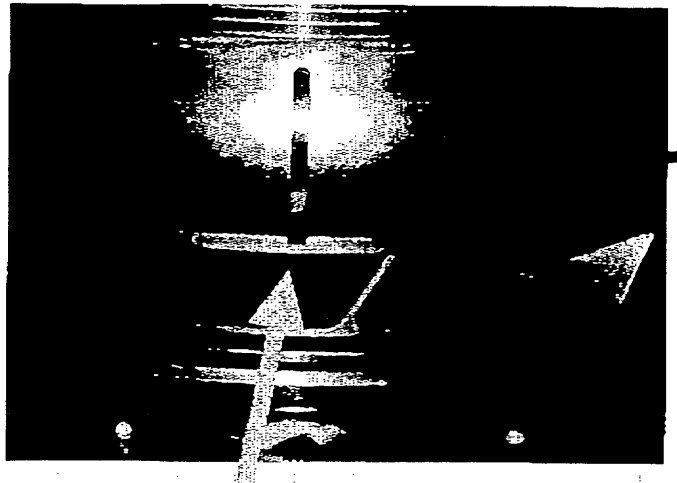
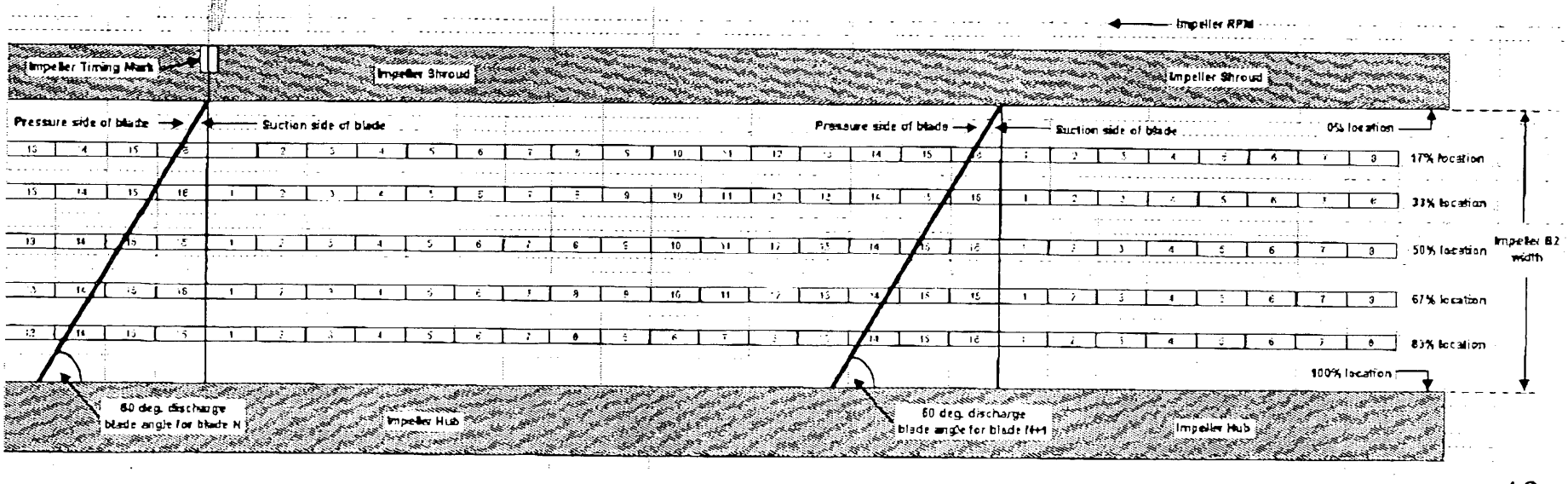


Impeller timing mark on shroud



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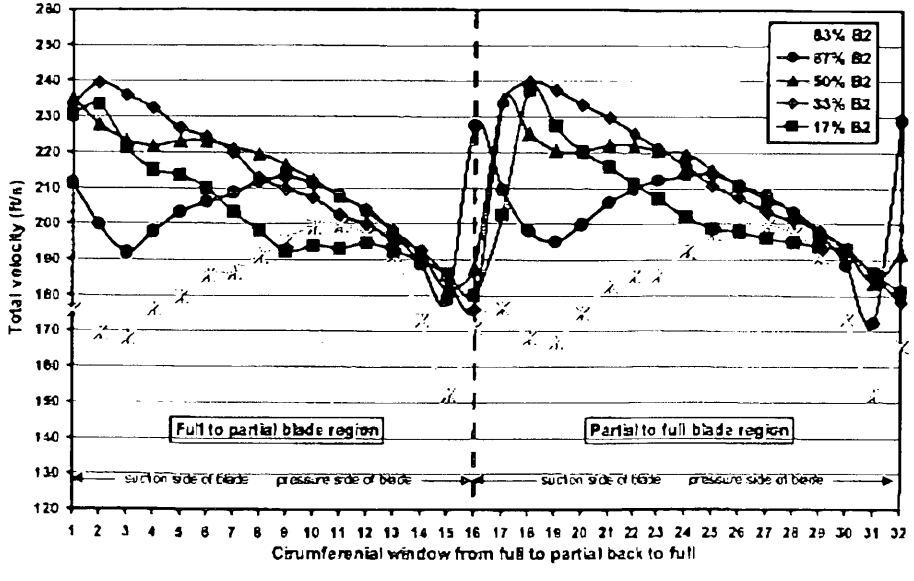
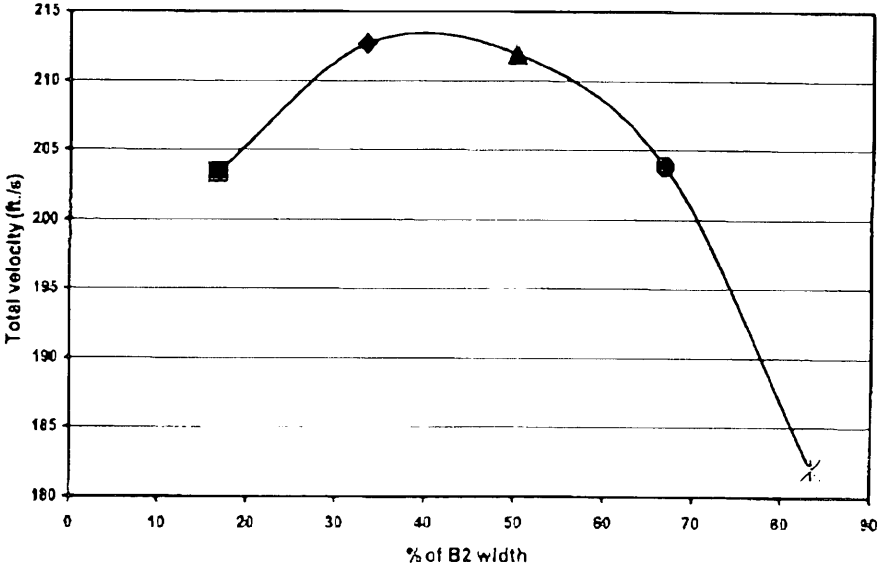
1996 Data: Total velocity at discharge of high head impeller at 100% Qd



1996 Data: Total velocity at discharge of high head impeller

Multi-window data converted to ensemble averaged



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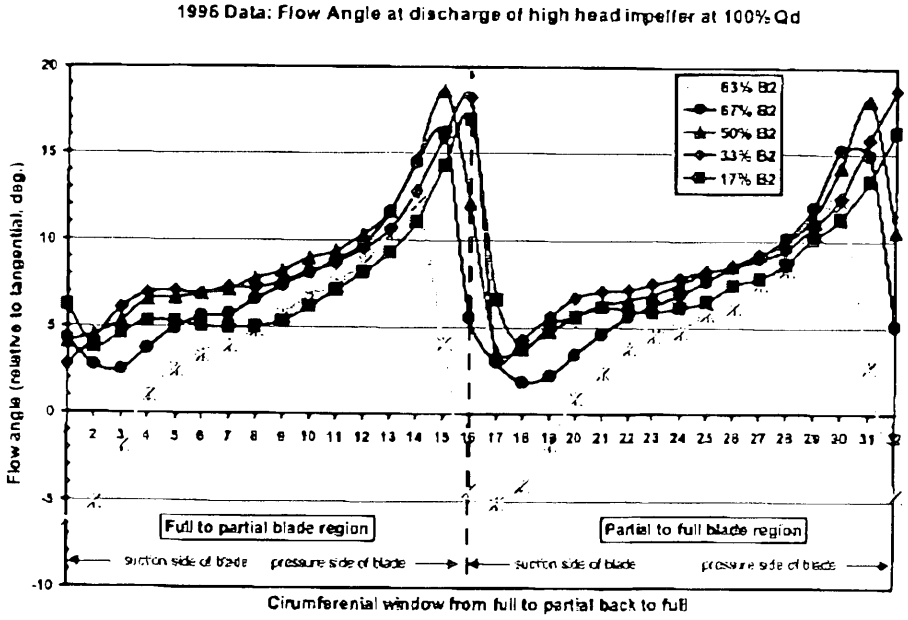

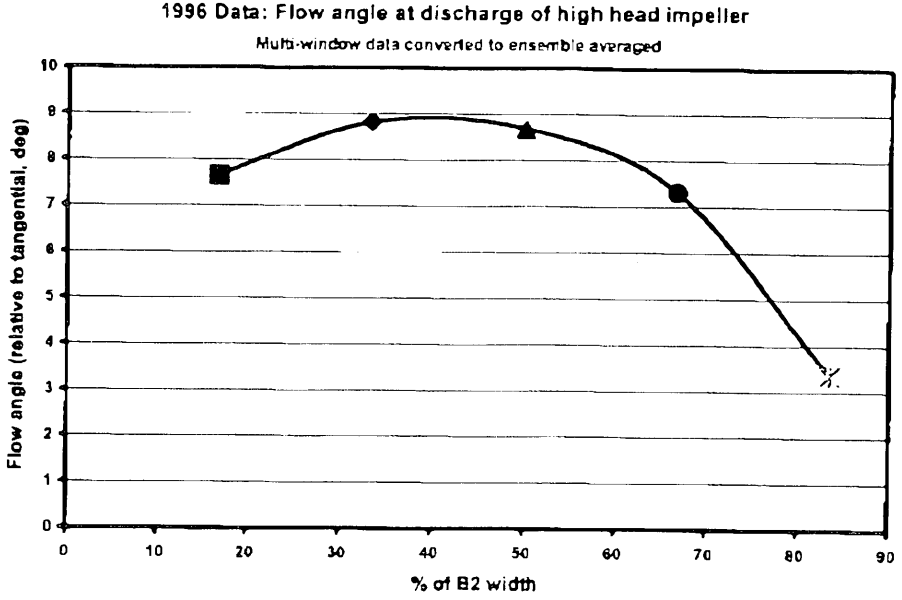

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- Laser velocimeter data collected over 2 days at impeller discharge across B2
  - 51 total laser data files
  - 4 flow rates: 100% , 80% , 30% , 120% Qd (Qd = 1210 gpm)
    - 100% first: verify same flow as 1996
    - 80% second: contract objective
    - 30% third: anchor CFD at low Qd
    - 120% fourth: anchor CFD at high Qd
  - 11 points across B2: 0, 10, 20, . . . 90, 100% (B2 = 0.58")
  - Laser data collected was ensemble averaged (~ Kiel probe)
  - Facility & pump overall performance data collection (monitoring files) active during laser data collection (~ 3 min)
    - Post-processing helped reveal timing of tester damage

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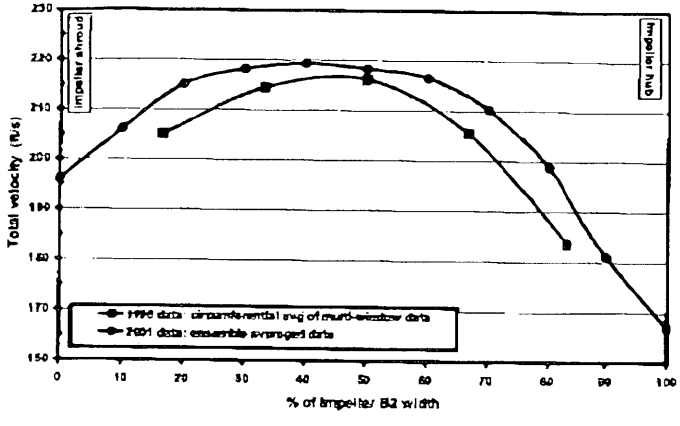
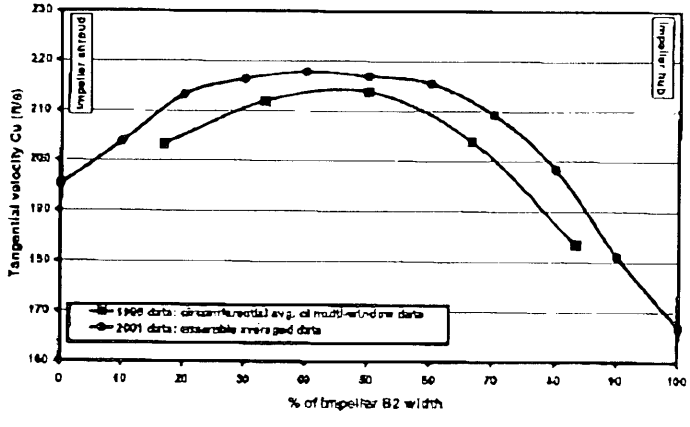
Total Velocity



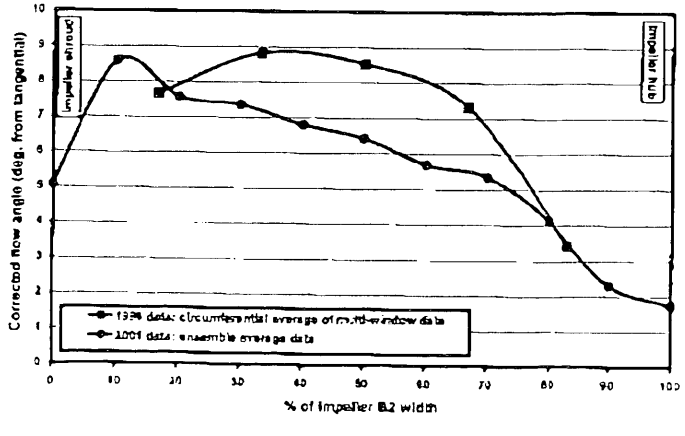
1996

2001

Cu Tangential Velocity



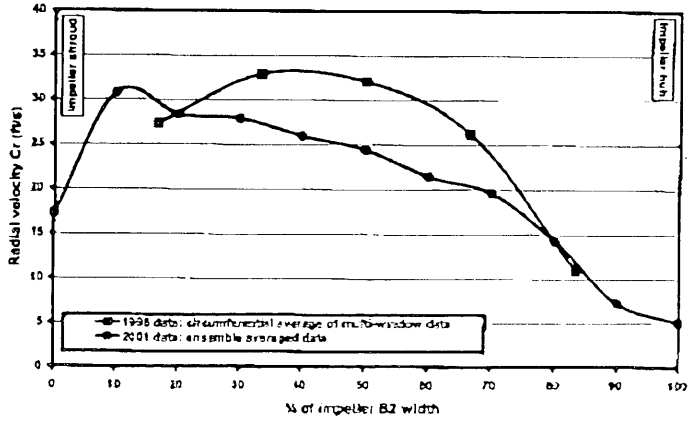
Flow Angle



1996

2001

Cr Radial Velocity



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- Key factors that may explain differences between 2001 and 1996 data
  - Same impeller design, different unit
    - 2001 impeller fabricated by same vendor using existing CNC tape
    - 2001 impeller B2 0.010" wider than 1996 impeller
  - Greater leakage flow through impeller laby seal
    - Laby seal was more worn than in 1996 (new)
  - Subtle differences in alignment procedures could lead to different angle correction factors

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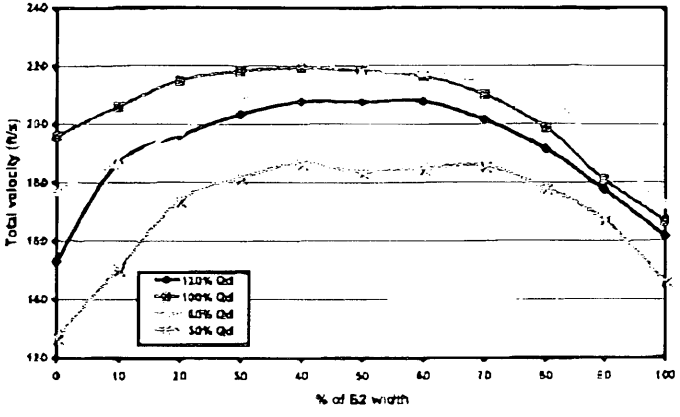
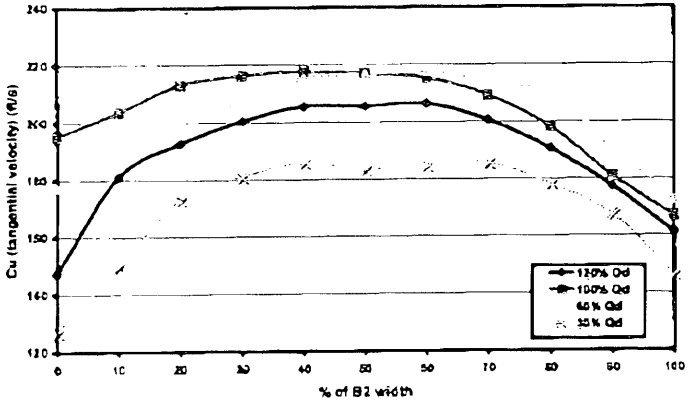
Total Velocity

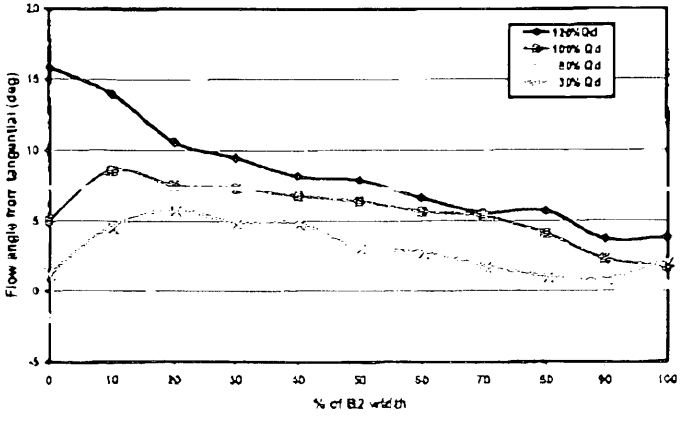


120%
100%
80%
50%

Cu Tangential Velocity



Flow Angle



120%
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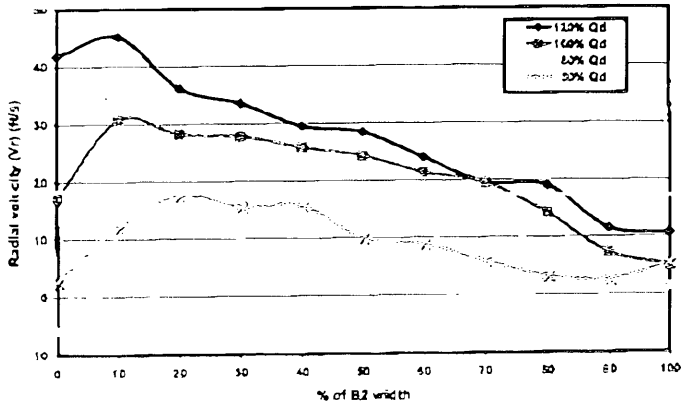
50%

Cr Radial Velocity



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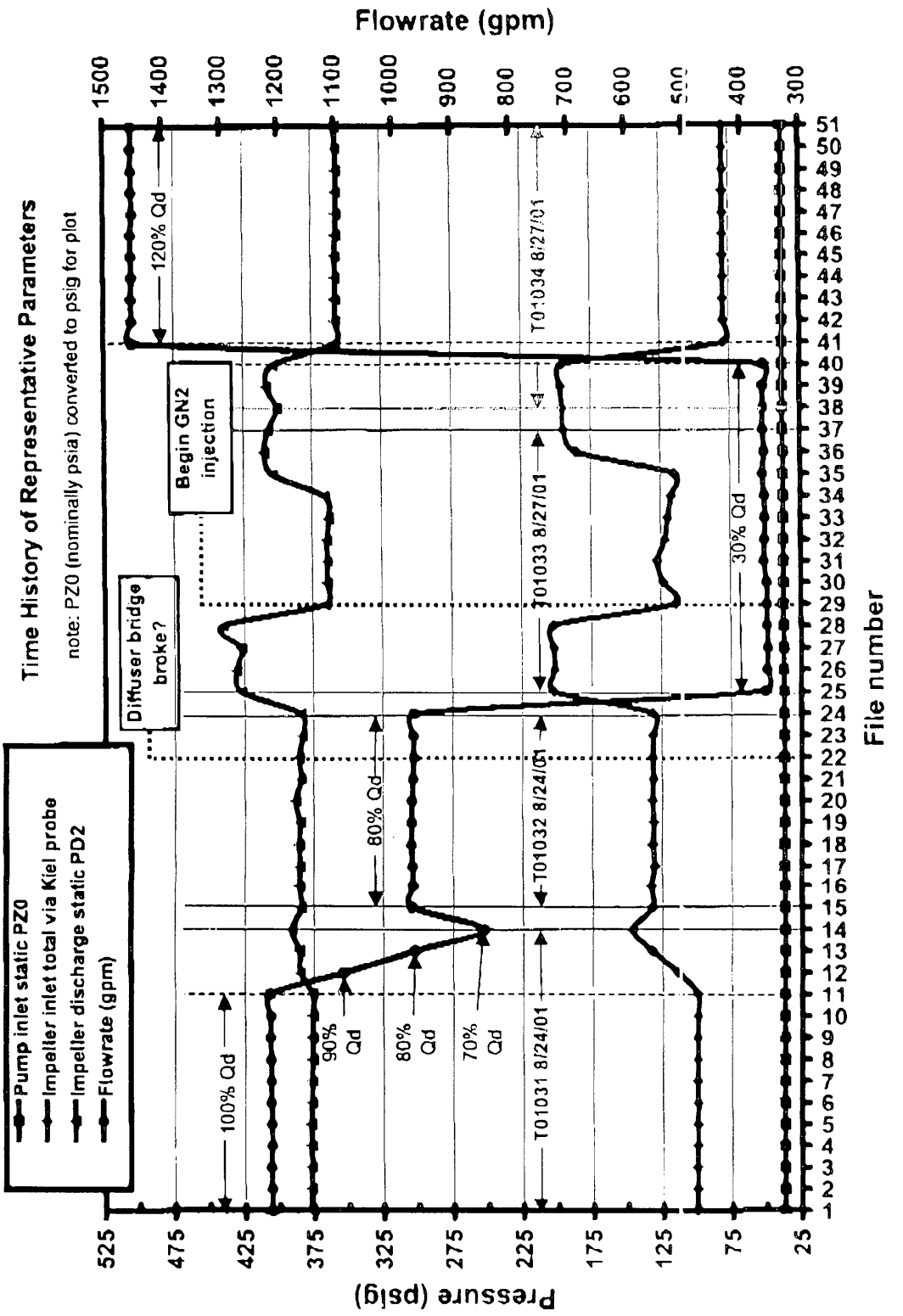

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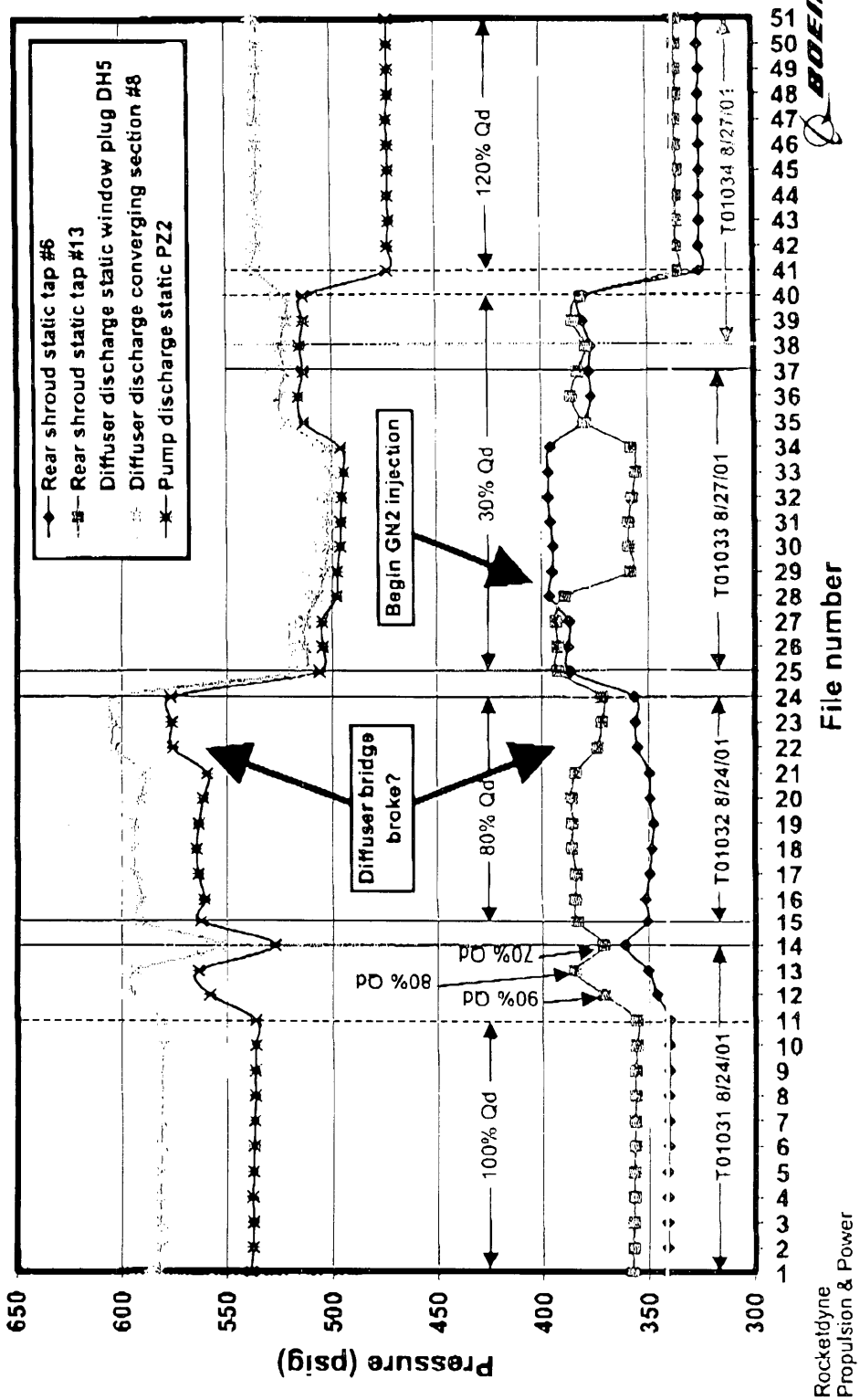
Time History of Representative Parameters



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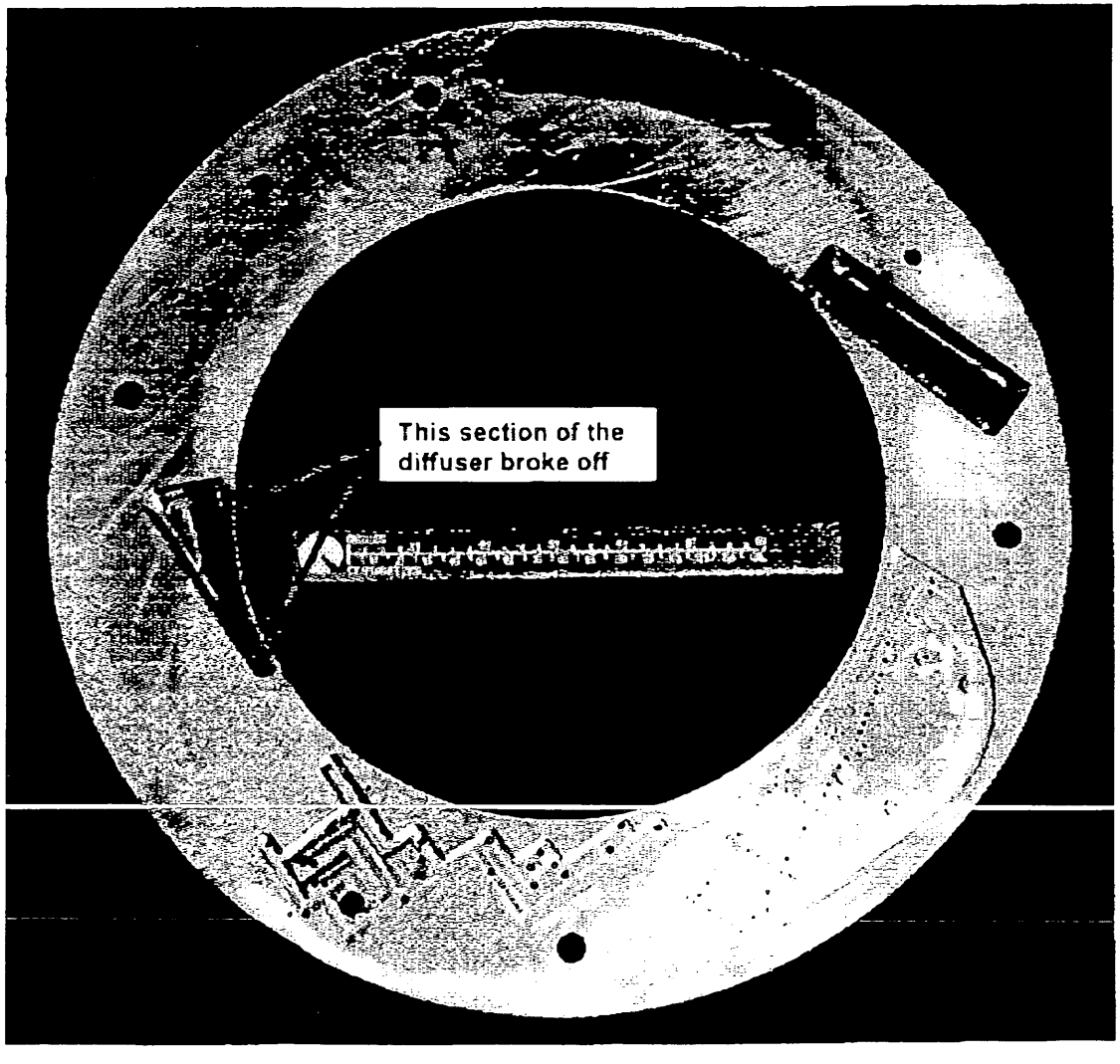
View of Pre-Test Diffuser Shows Intact Bu[illegible]



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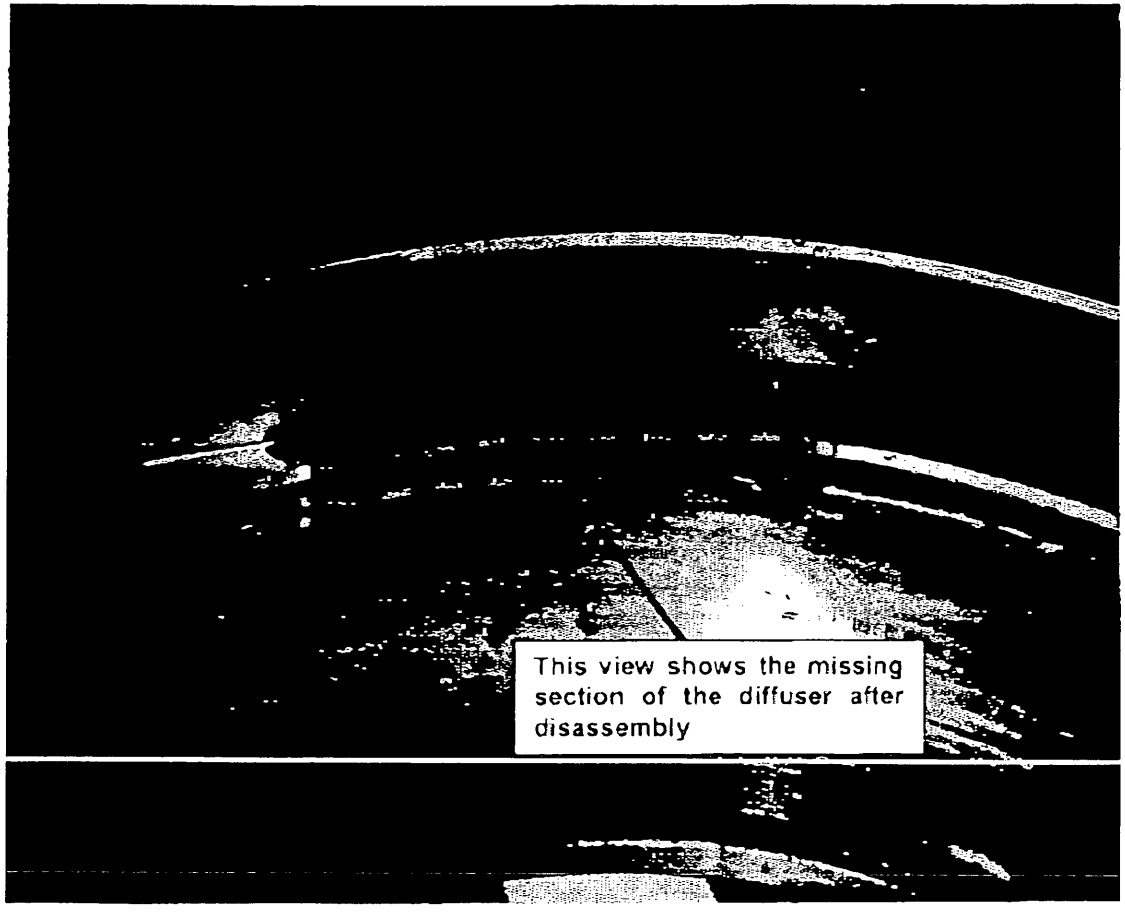

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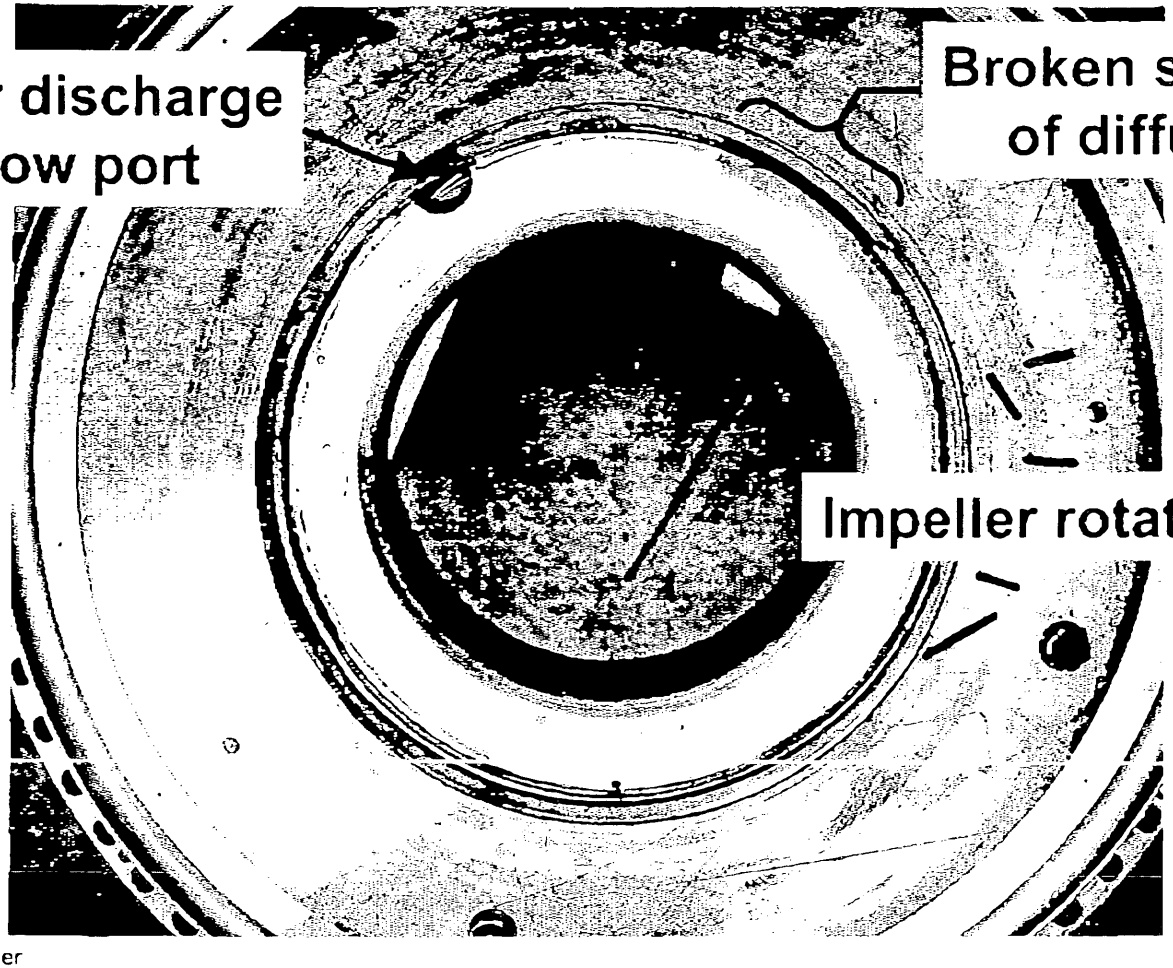

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- First data sets
  - 100% Qd data from 2001 reasonably close to 1996 data
  - 80% Qd data from 2001 probably OK up to certain point
    - Data at 0, 10, 20, 30, 40, 50, 60, 70% B2 OK
    - Data at 80, 90, 100% B2 occurred after diffuser piece broke
- Damage was not detected at this point and testing continued
  - Data rate problems encountered at 30% Qd
  - Solution: inject metal coated glass microspheres into fluid to boost data rate (higher SNR)
  - GN2 used to inject seeds leaked into water
    - Monitoring files showed this caused loss of impeller head with probable impact on discharge flow field

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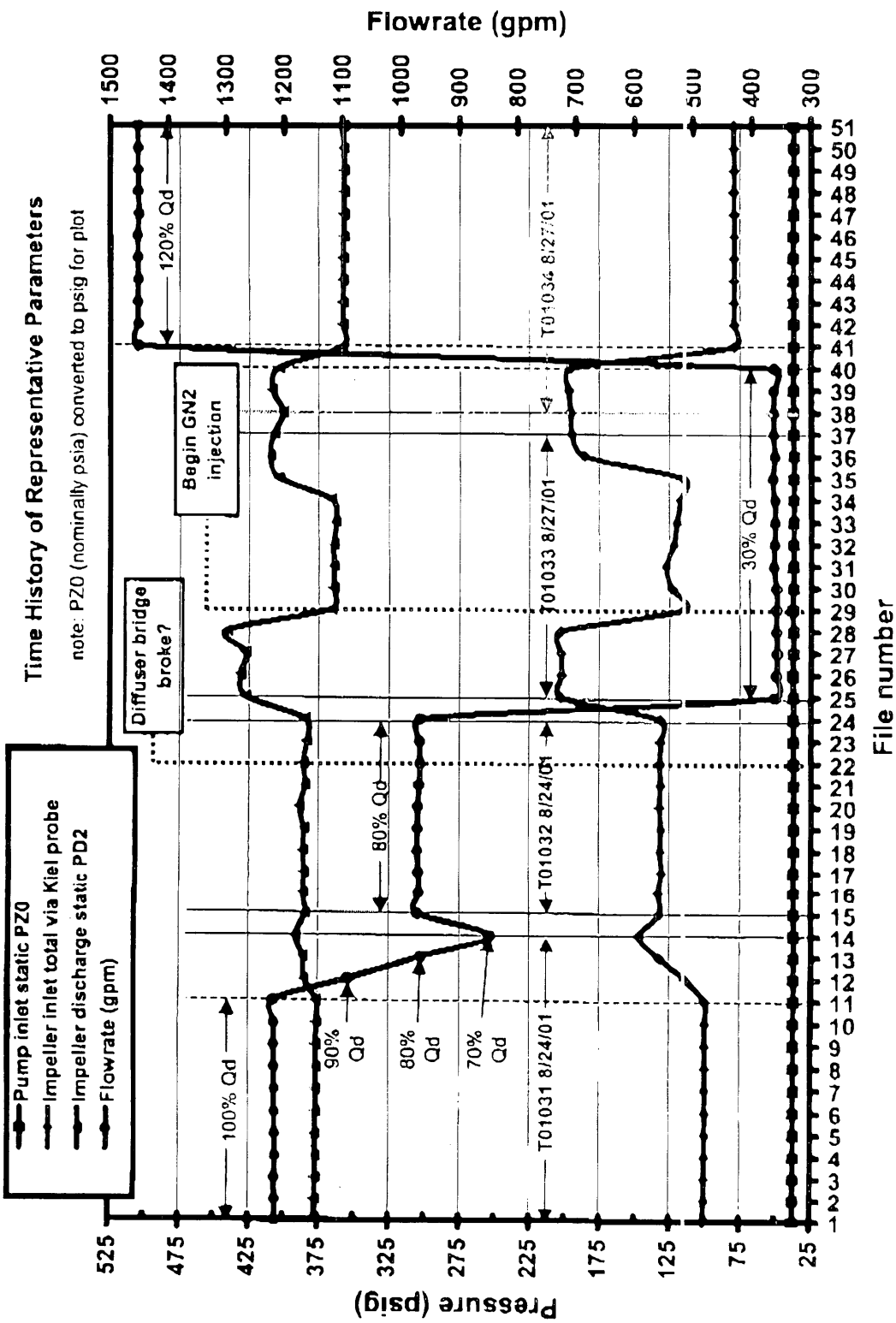

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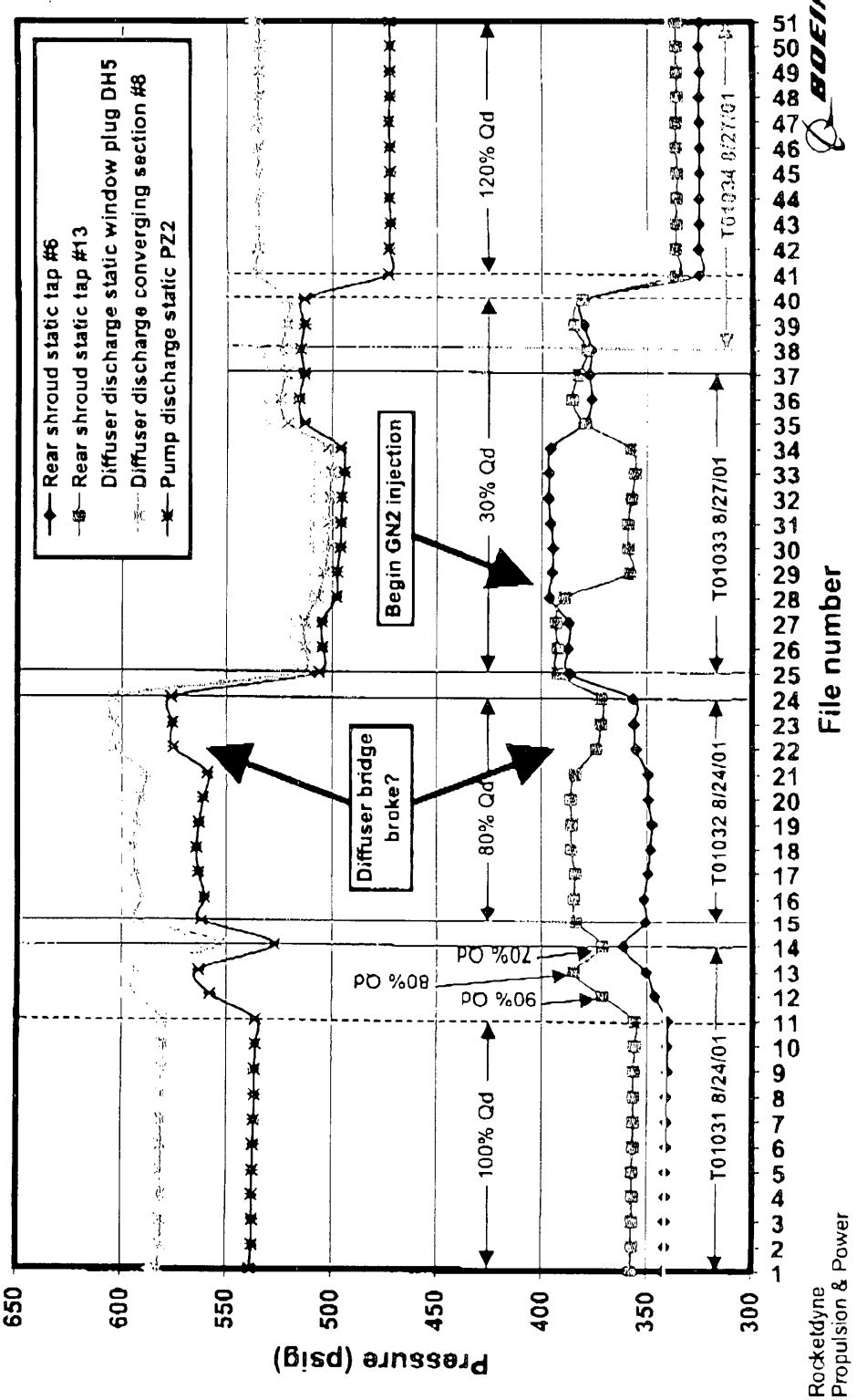
Time History of Representative Parameters



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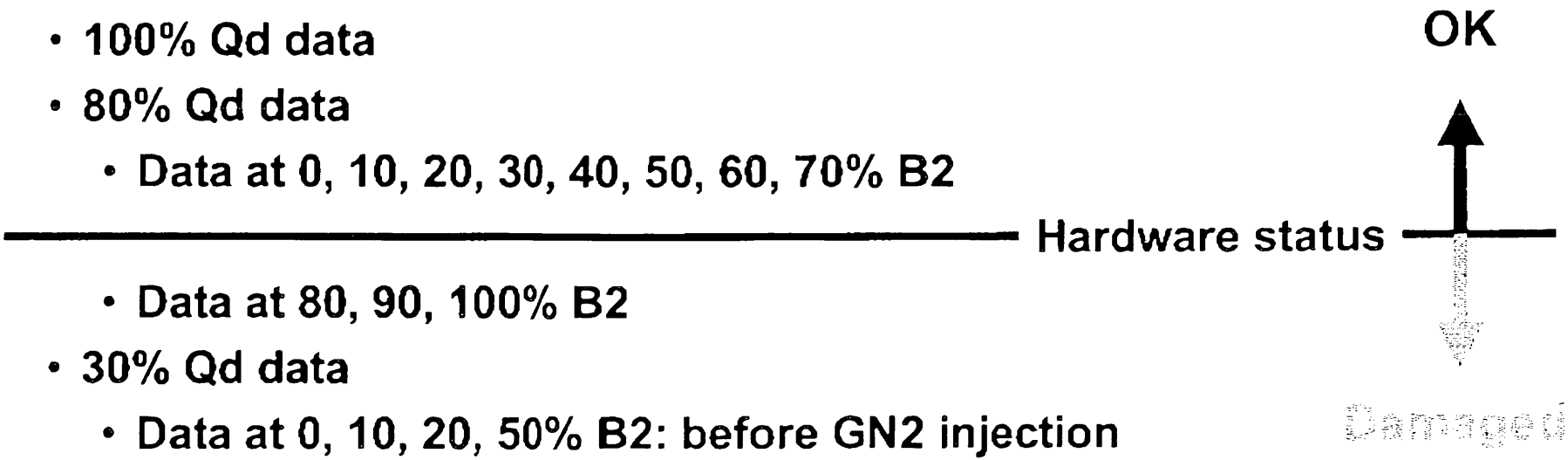
Test Facility Summary

Four flowrate summary

- 100% Qd data
- 80% Qd data
  - Data at 0, 10, 20, 30, 40, 50, 60, 70% B2



  - Data at 80, 90, 100% B2
- 30% Qd data
  - Data at 0, 10, 20, 50% B2: before GN2 injection
  - Data at 30 & 40% B2: GN2 in water
  - Data at 60, 70, 80, 90, 100% B2: after GN2 escape
- 120% Qd data
  - Data at 0, 10, 20, . . . 90, 100% B2

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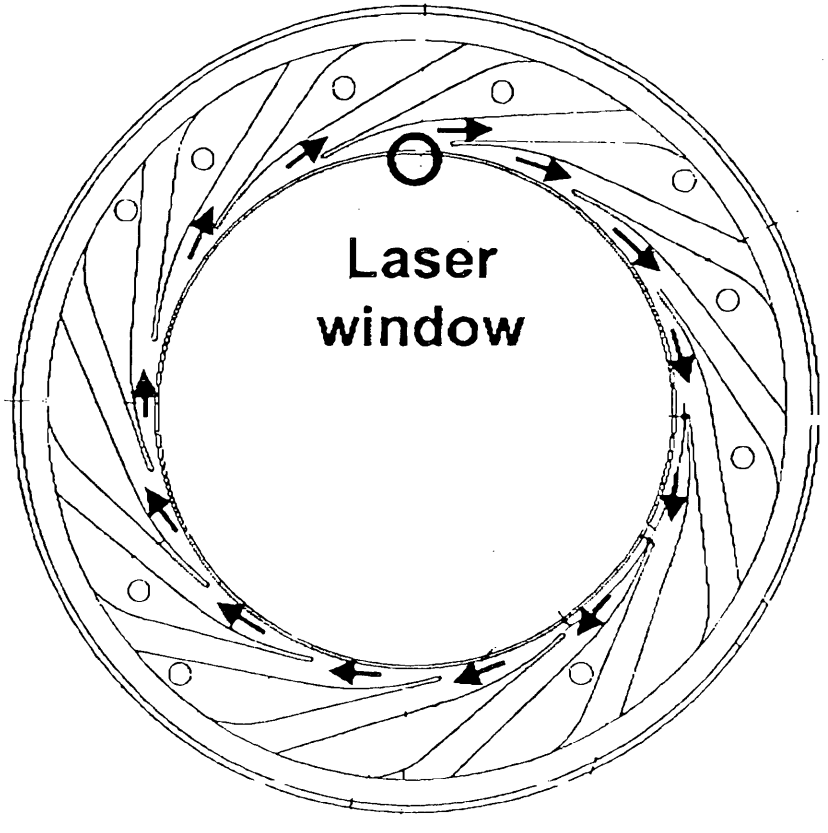
Water Flow Calculation Using Laser Data Integrity

- Area-averaged flowrate calculation using laser data yields integrated flowrate: compare to actual flowmeters
  - *Assume impeller exit flow measured at one location with respect to a particular diffuser vane is same for all diffuser vanes*
  - Tester had single window located at fixed location relative to a specific pair of diffuser vanes



PAGE.29

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Calculation methodolgy

- Use Excel to determine polynomial curve fit to 11 points of Cr data across impeller B2 at each of 4 flowrates
- Using curve fit equation, set up SS to calculate velocity at 100 points across B2 (interpolated)
- Calculate average velocity data from n and n+1 points
- Assign that average velocity to cell bordered by n and n+1 points
- Calculate flow rate in that cell based on averaged velocity
- Sum all averaged velocity-based flowrates in all 100 cells to get total flow rate

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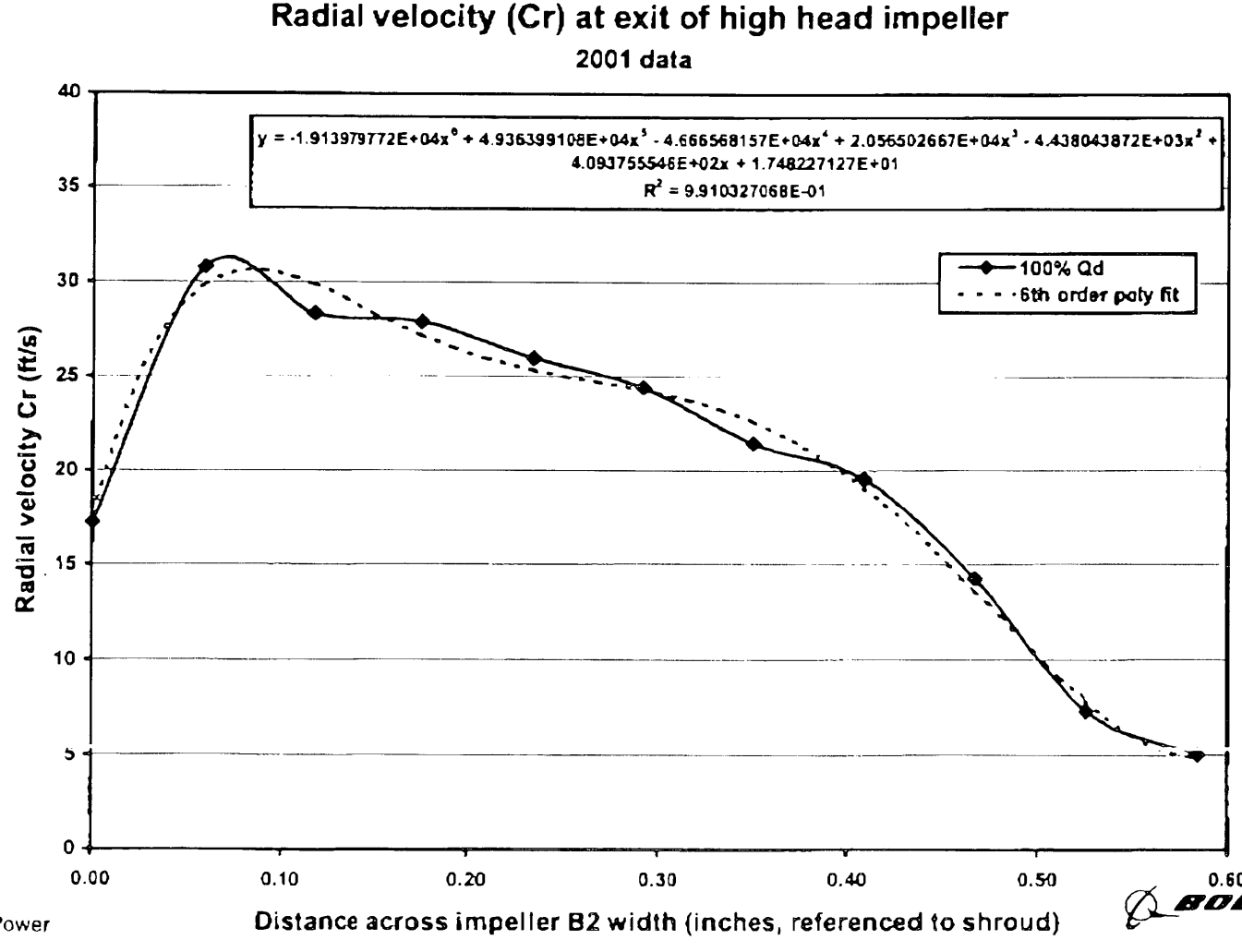

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% B2 (%)	distance (in)	ring area (in^2)	100% Qd calculations: calculated radial velocity (ft/s)	avg (ft/s)	(in/s)	Q calc. (gpm)
0	0.000000	0.168810	17.482271			
				18.603988	223.247855	9.672721
1	0.005840	0.168810	19.725704			
				20.707972	248.495666	10.766640
2	0.011680	0.168810	21.690240			
				22.544395	270.532738	11.721447
3	0.017520	0.168810	23.398550			
				24.135316	289.623796	12.548610
4	0.023360	0.168810	24.872083			
				25.501593	306.019117	13.258975
5	0.029200	0.168810	26.131103			
				26.662916	319.954995	13.862778
6	0.035040	0.168810	27.194729			
				27.637849	331.654193	14.369673
7	0.040880	0.168810	28.080970			

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Integrated Calculation Results Comparison

Flow as % of Qd (%)	Target flowrate (gpm)	Avg. measured flowrate (gpm)	Integrated calculated flowrate	
			(gpm)	(% of attained)
120	1452	1451.9	1428.8	98.4
100	1210	1214.9	1106.8	91.1
80	968	969.6	364.1	37.6
30	363	358.5	501.9	140

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Interpretations of results

- Close continuity match (91%) at 100%Qd suggests data is approximately correct
  - Similarity between 1996 data and 2001 data supports this assertion
- Close continuity match (98%) at 120% Qd could suggest damage to diffuser and impeller may not have significantly altered flow field, components working about as designed
- Therefore, continuity mis-match at 80% and 30% Qd might be evidence of real flow phenomena
  - Stall mechanism at work?
  - Mass inbalance through diffuser vanes?

PAGE:34

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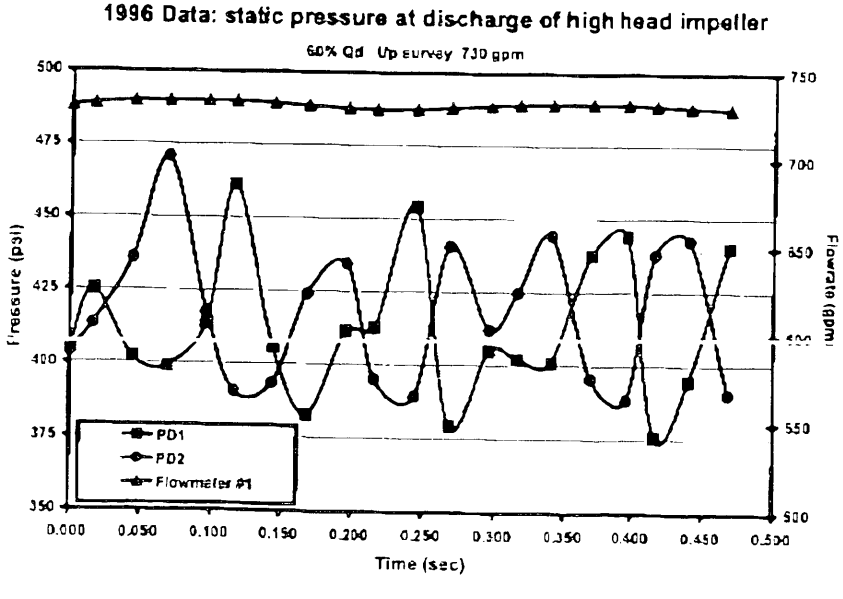
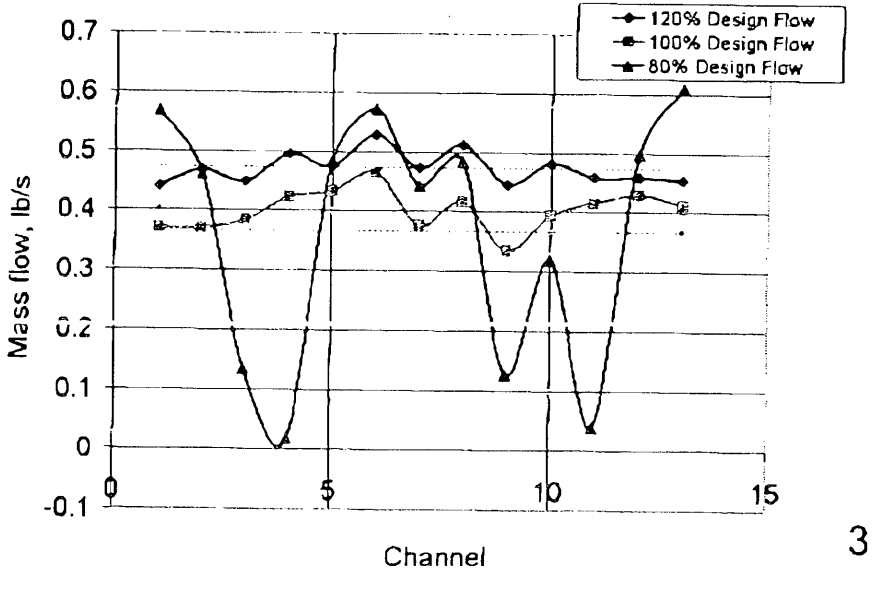
- Interpretations of results
  - 1996 pressure data at impeller discharge shows pressure fluctuations at 60% Qd
  - CFD calculations show vane-to-vane mass flow inbalance at 80%
  - More data analysis with tie-in to pressure data needed





Deep Throttle Turbopump Technology Testing

- Program was setup to demonstrate wide flow range diffuser technologies
- Testing phase of contract to provide data to anchor initial designs partially successful
- Data collected suggest flow phenomena exists at off-design flowrates
  - Cause and mechanism not well understood
  - Data analysis not complete before end of funding
  - Data can be better understood with more analysis and comparison to pressure measurements