UNIPI Contribution to BFBT Benchmark using RELAP5-3D© system code

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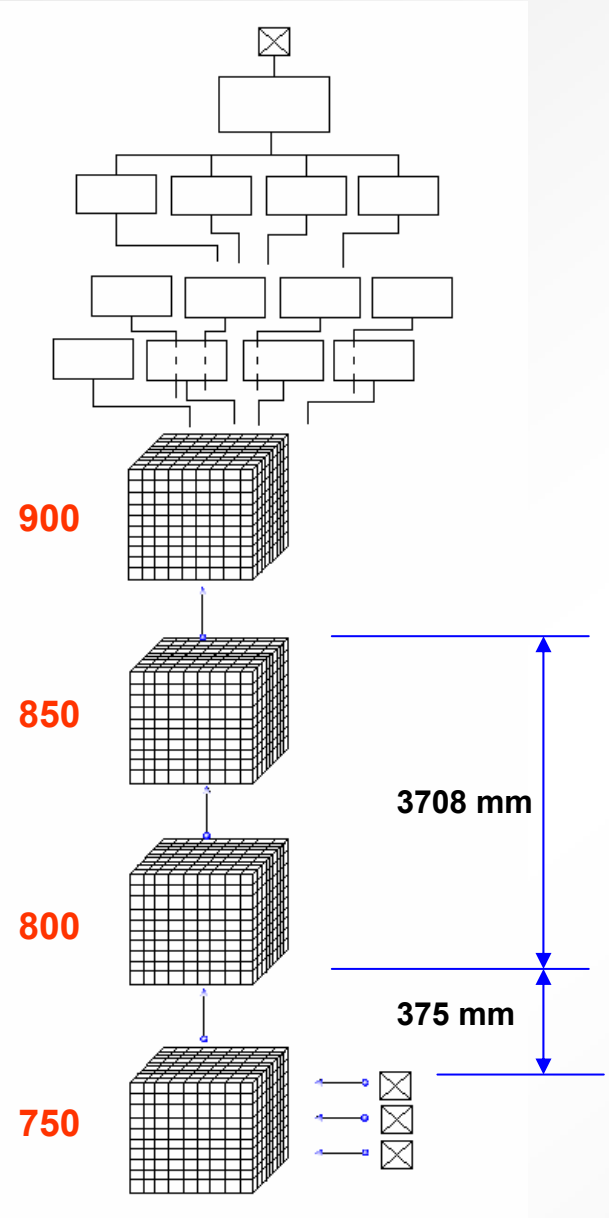
INTRODUCTION

- NUPEC BWR Full-size Fine-mesh Bundle Tests (BFBT) → large amount of fine mesh experimental data available for a BWR Test Bundle
- High Resolution of experimental data
- Phase 1:
  - Void distribution benchmark (SS & Transient)
- Phase 2:
  - Pressure drop benchmark (1 Phase, 2 Phase)
  - Critical Power Benchmark

OBJECTIVES

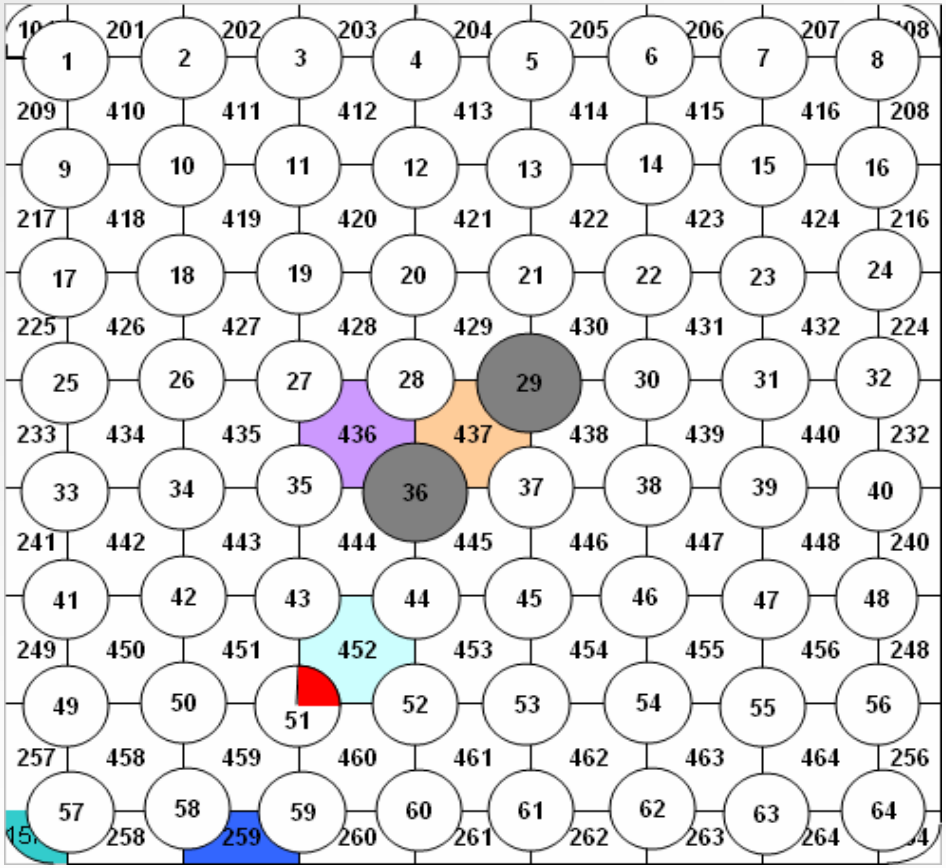
- To assess the capabilities of RELAP5-3D© in simulating BWR core sub-channels systems
- To contribute to the development and validation of two-phase models for CFD codes
- To assess the UNIPI methodology for TH nodalization development
- Possibility to Assess the CIAU capability for Uncertainty Evaluation of Calculated results

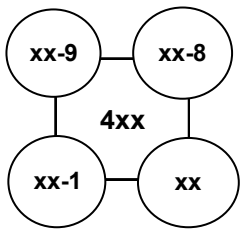
THERMAL-HYDRAULICS MODELING 1/6



- Number of
  - Hydraulic Volumes: 2939
  - Junctions: 8122
  - Heat Structure: 6144
  - Mesh Points: 43008
- Components (3D):
  - 750 → Lower Plenum
  - 800 → Lower FA part
  - 850 → Upper FA part
  - 900 → Upper Plenum
- Boundary & Initial Conditions imposed by 1D components

THERMAL-HYDRAULICS MODELING 2/6

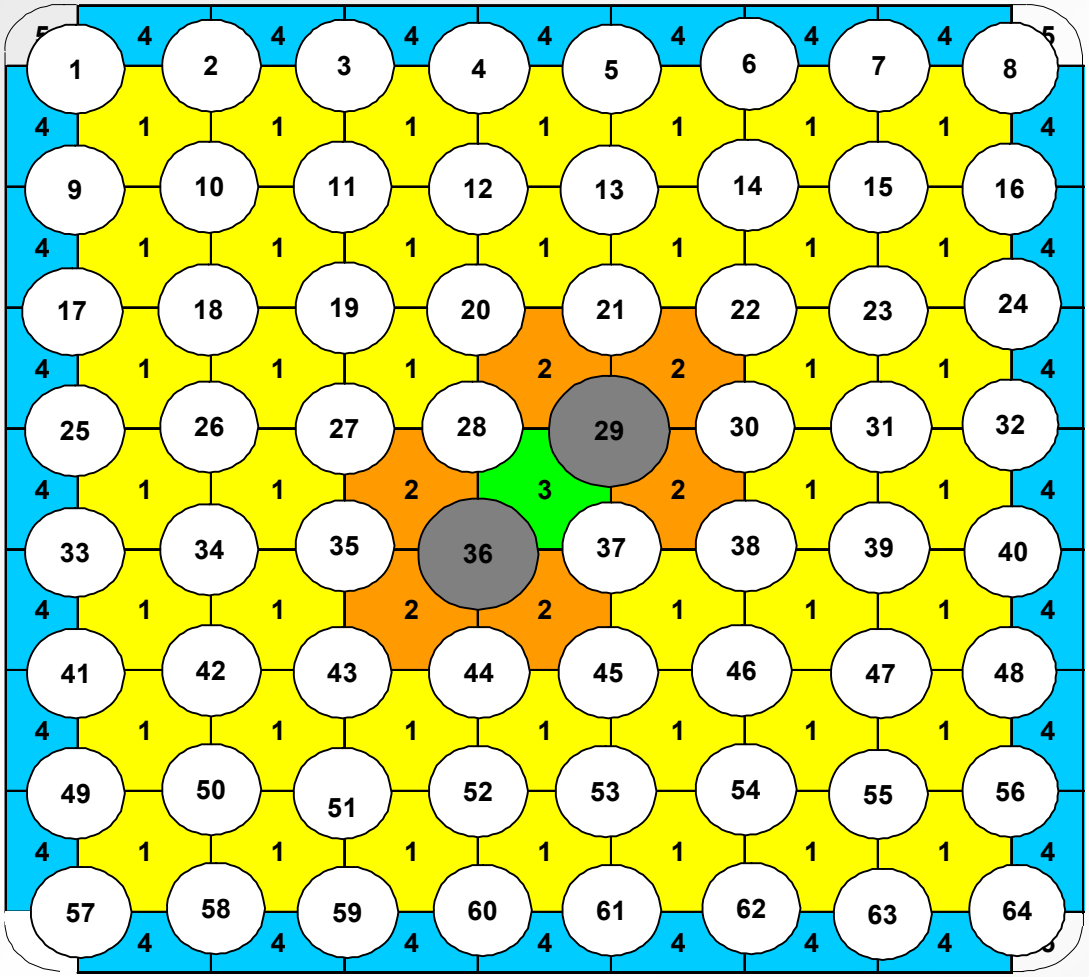




Cell Numbering

- 3D volumes representing flow areas of FA
- FA divided in:
  - 9 x 9 volumes in XY plane
  - 24 axial planes (154.5 mm height)
- Further two 3D volumes 9x9x6 (750 & 900) for modeling inlet and outlet
- Flow rate Inlet by 3 Equal Side (Y-direction) Time Dependent Volumes Located 375 mm below BAF
- No Initial Flow Distribution (x-y-z dir) have been defined

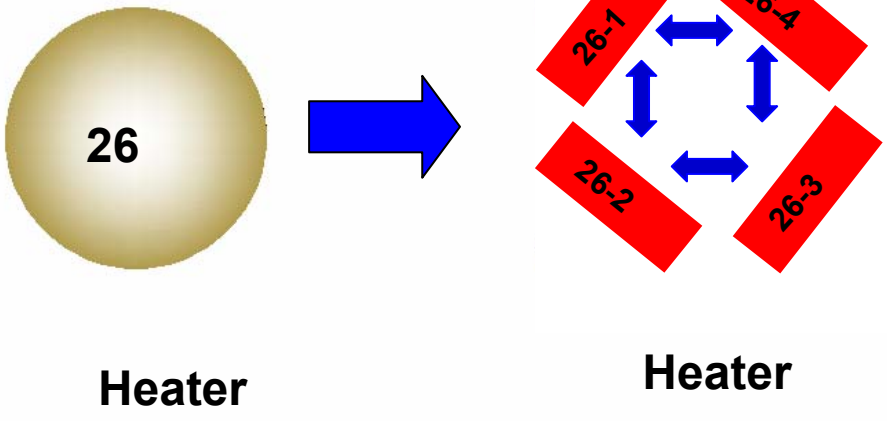
THERMAL-HYDRAULICS MODELING 3/6



Type of Volume

- 5 Types of Volumes with different Hydraulic and heated diameters in x-y and z directions
- Axial Pressure loss coefficients Kf = 1.2 (at seven axial levels) as recommended in Benchmark
- No Kf have been defined in X-Y directions

THERMAL-HYDRAULICS MODELING 4/6



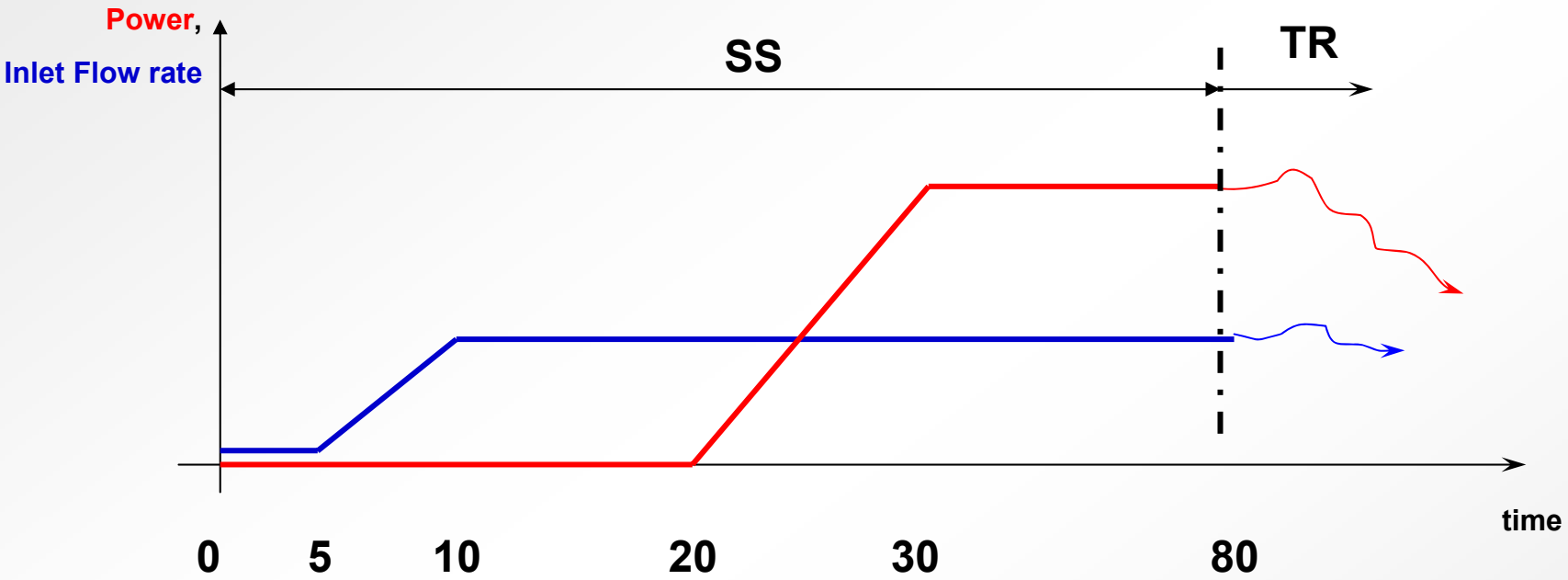
- Cylindrical heater → modeled by 4 slabs HS thermally connected
  - Use of RELAP5-3D© conduction enclosure model for HS-HS thermal exchange
  - Conserved:
    - External Heat Exchange surface (Total Surface)
    - Heat Capacity (Total Volume)
    - System Time Constant (about 3 sec in calculation)

SLAB to SLAB conductance estimated by ANSYS – FE 2D Heat Conduction model

Implemented in RELAP

THERMAL-HYDRAULICS MODELING 5/6

How the SS Calculations have been performed



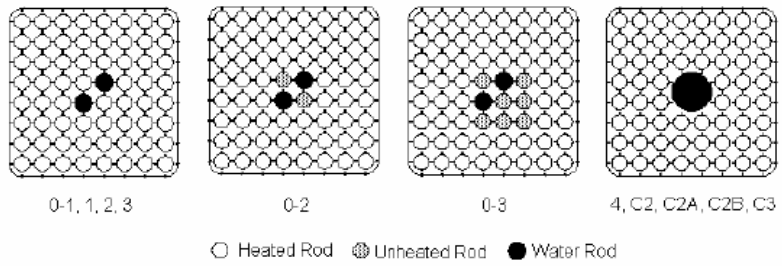
Maximum Time-Step = 10^{-3} sec

1 SS Calculation: about 2 days

THERMAL-HYDRAULICS MODELING 6/6

WORK PERMORMED

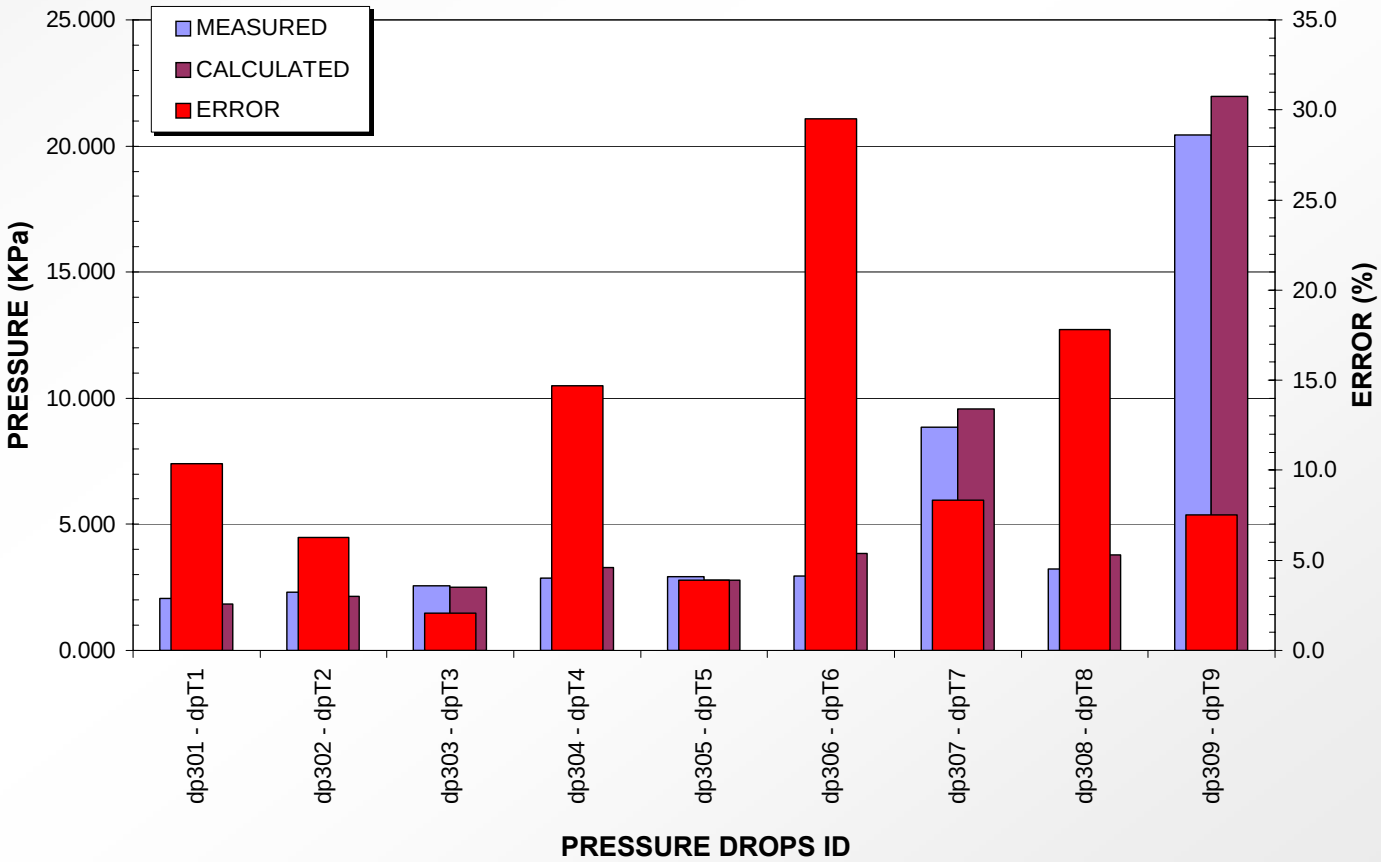
- All 4 different FA modeled
- All Calculations are **PRELIMINARY**
- Executed tests:
  - Void fraction - SS
    - FA 0-1 (all 3 Tests)
    - FA 0-2 (all 3 Tests)
    - FA 0-3 (all 3 Tests)
    - FA 1 (2 over 3 Tests)
    - FA 4 (1 over 3 Tests)
  - Void fraction - transient
    - Turbine Trip
  - Critical Power – Pressure Drop
    - 1 case for 1Φ-PD and 1 case for 2Φ-PD



SINGLE PHASE PRESSURE DROPS: P70033

TEST P70033	CALC	EXP	DIFF %	MAX CALC	MAX EXP	MIN CALC	MIN EXP
PRESSURE IN	7.173	7.170	0.292				
PRESSURE OUT	7.151	7.150	0.174				
TEMP IN	558.050	557.850	0.036				
FLOW RATE IN	5.639	15.278	-63.092				

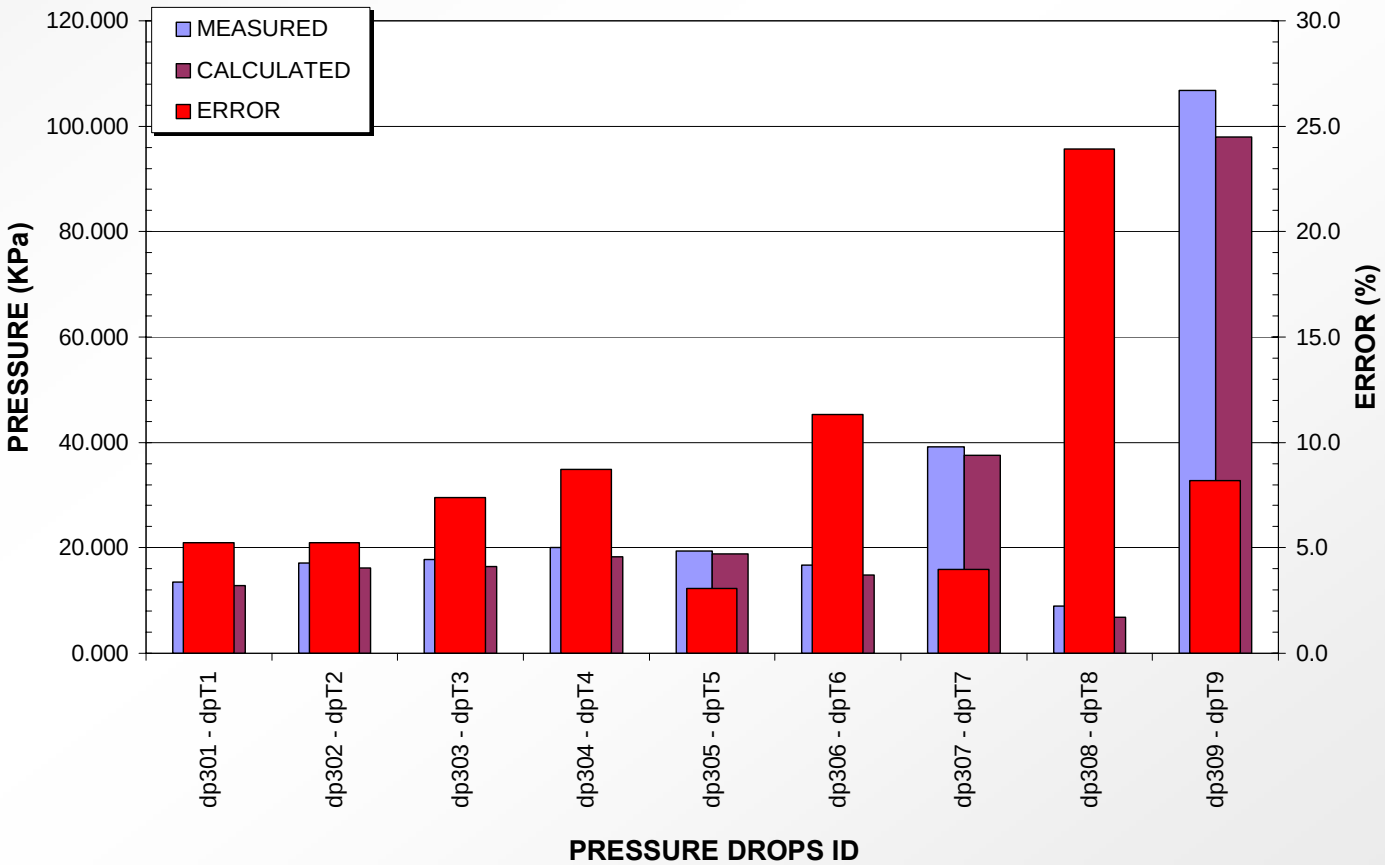
PRESSURE DROPS	dp301 - dpT1	dp302 - dpT2	dp303 - dpT3	dp304 - dpT4	dp305 - dpT5	dp306 - dpT6	dp307 - dpT7	dp308 - dpT8	dp309 - dpT9
CALC	1.847	2.155	2.498	3.292	2.797	3.834	9.588	3.793	21.968
EXP	2.060	2.300	2.550	2.870	2.910	2.960	8.850	3.220	20.430
DIFF %	10.362	6.291	2.053	14.690	3.882	29.513	8.341	17.802	7.526



TWO PHASE PRESSURE DROPS: P70033

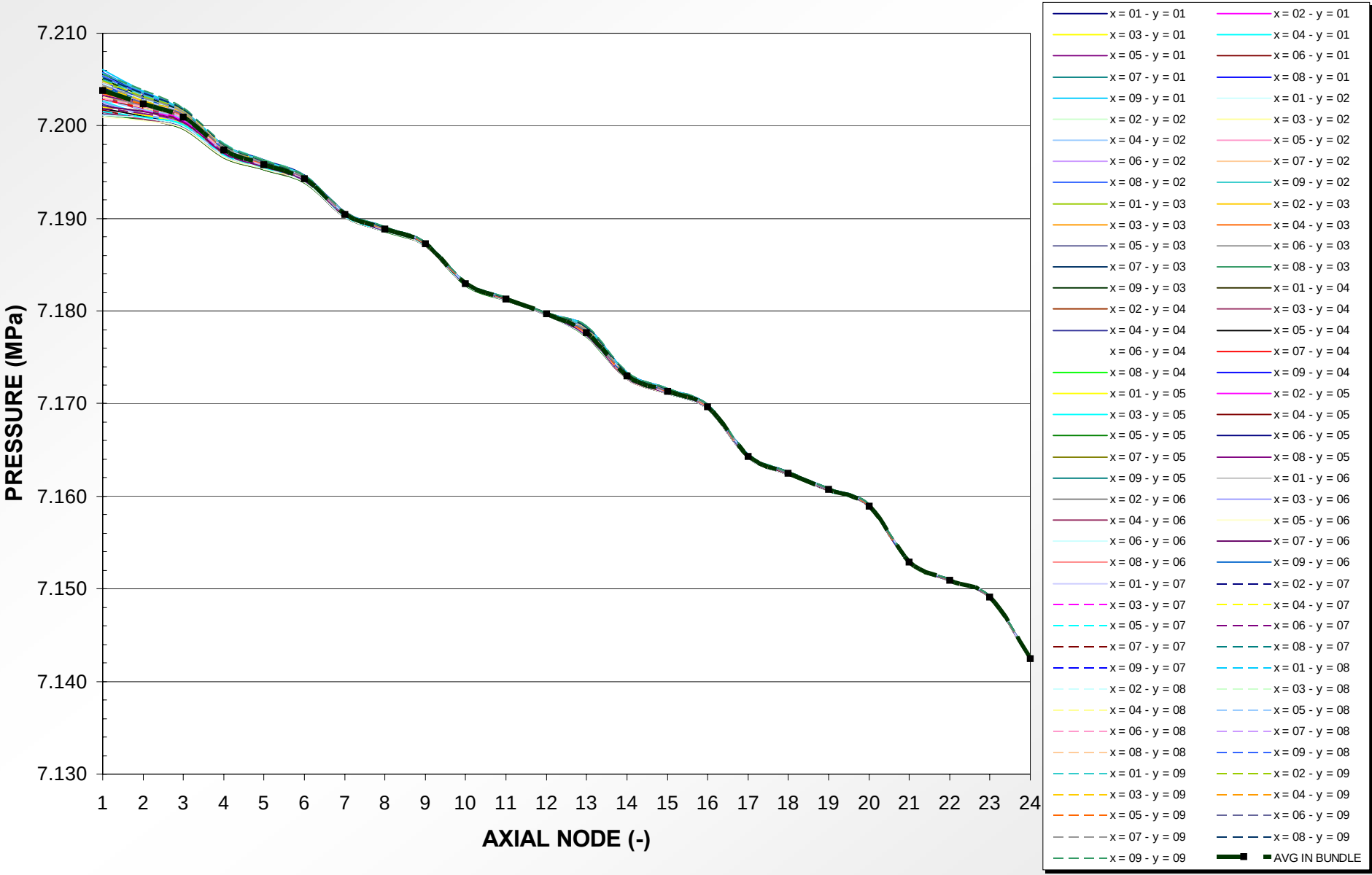
TEST P60011	CALC	EXP	DIFF %	MAX CALC	MAX EXP	MIN CALC	MIN EXP
PRESSURE IN	7.277	7.277	0.005				
PRESSURE OUT	7.189	7.170	0.260				
TEMP IN	0.000	551.150	-100.000				
FLOW RATE IN	0.000	15.250	-100.000				

PRESSURE DROPS	dp301 - dpT1	dp302 - dpT2	dp303 - dpT3	dp304 - dpT4	dp305 - dpT5	dp306 - dpT6	dp307 - dpT7	dp308 - dpT8	dp309 - dpT9
CALC	10.923	10.474	15.746	15.288	14.104	13.713	34.606	8.685	88.429
EXP	13.560	16.050	17.810	20.040	19.390	16.730	39.140	8.930	106.720
DIFF %	-19.444	-34.739	-11.589	-23.715	-27.260	-18.031	-11.583	-2.743	-17.139



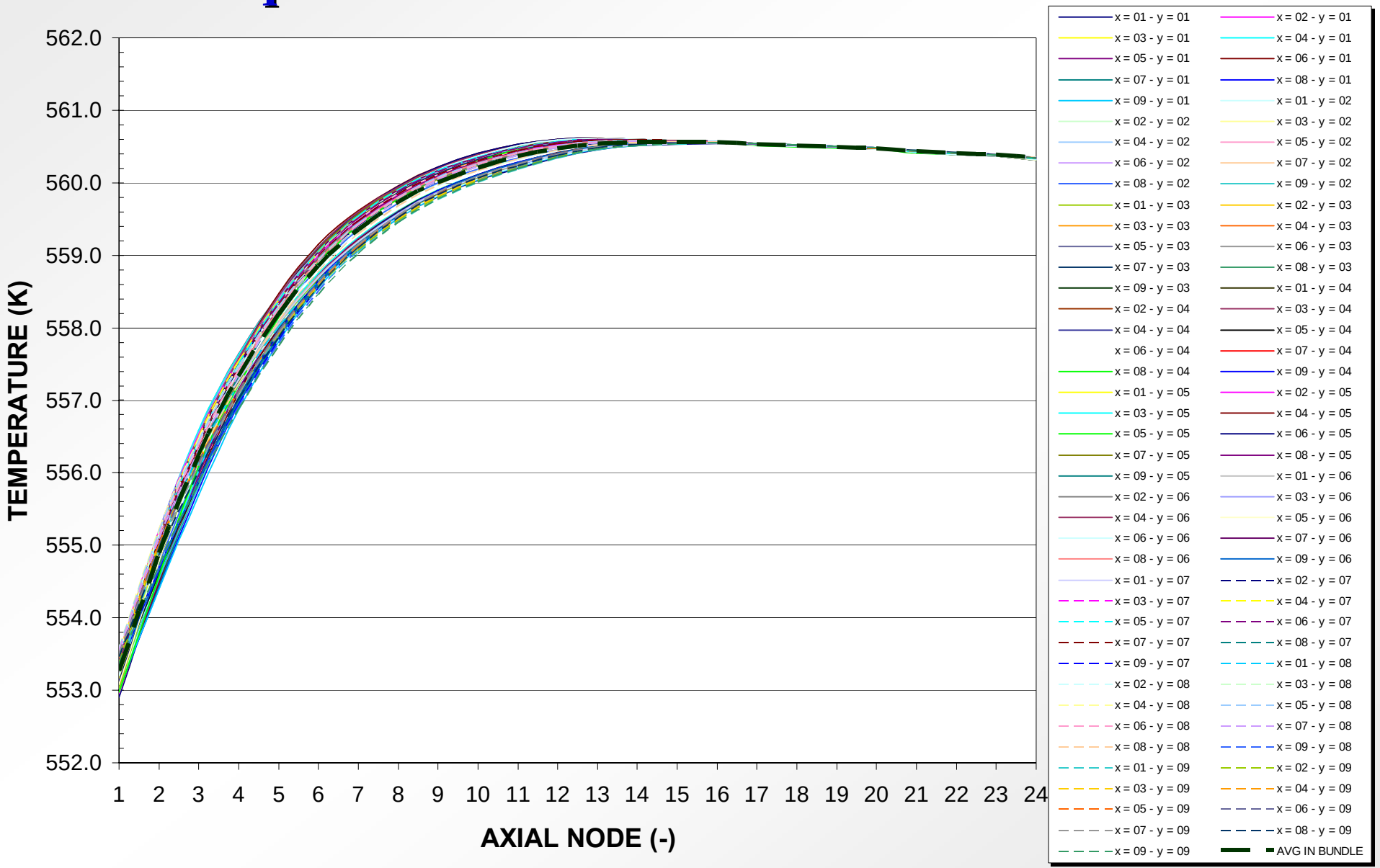
RESULTS: TEST 01-0011-58

Pressure Distributions in all Channels



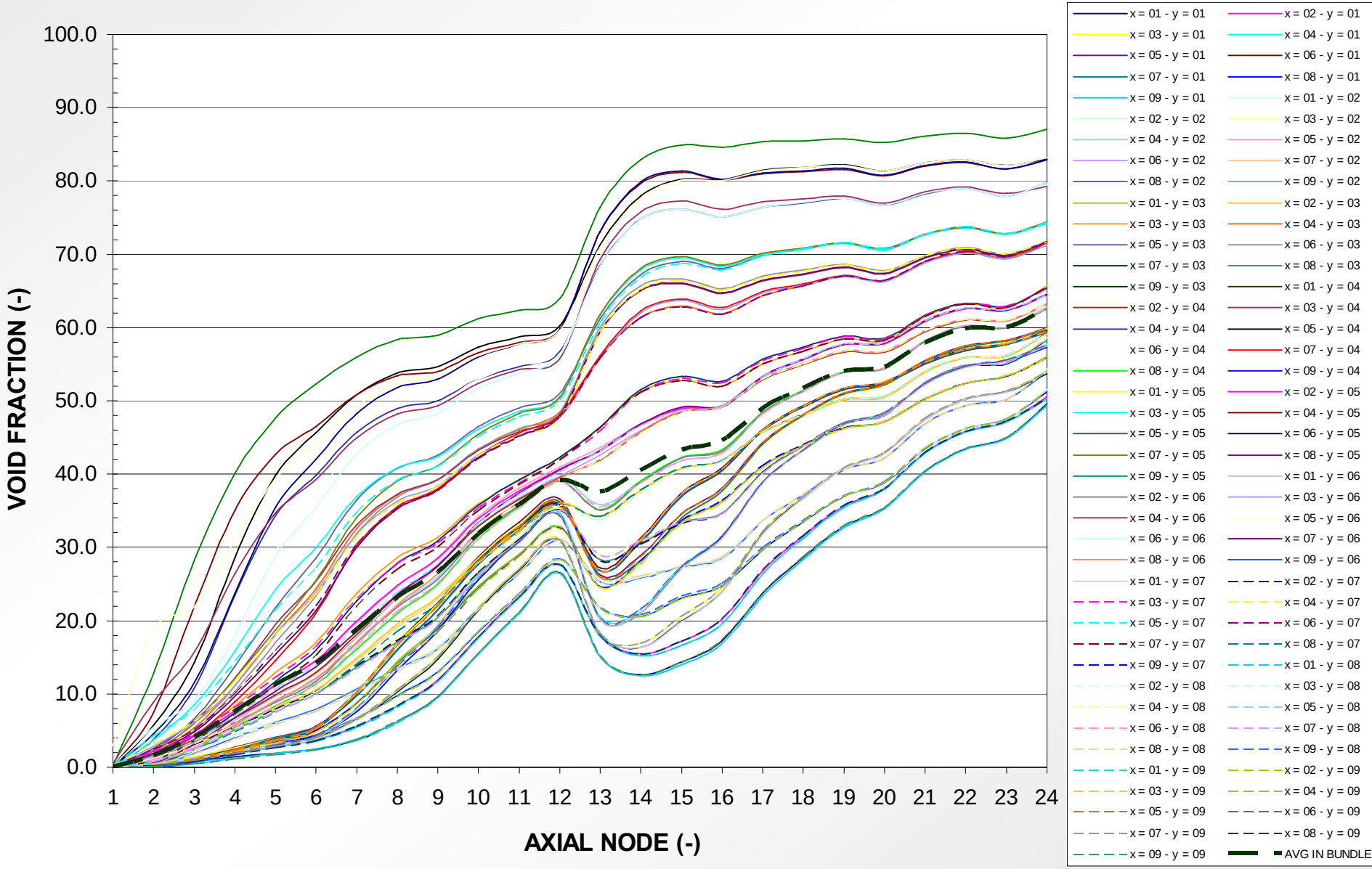
RESULTS: TEST 01-0011-58

Liquid Fluid Distributions in all Channels



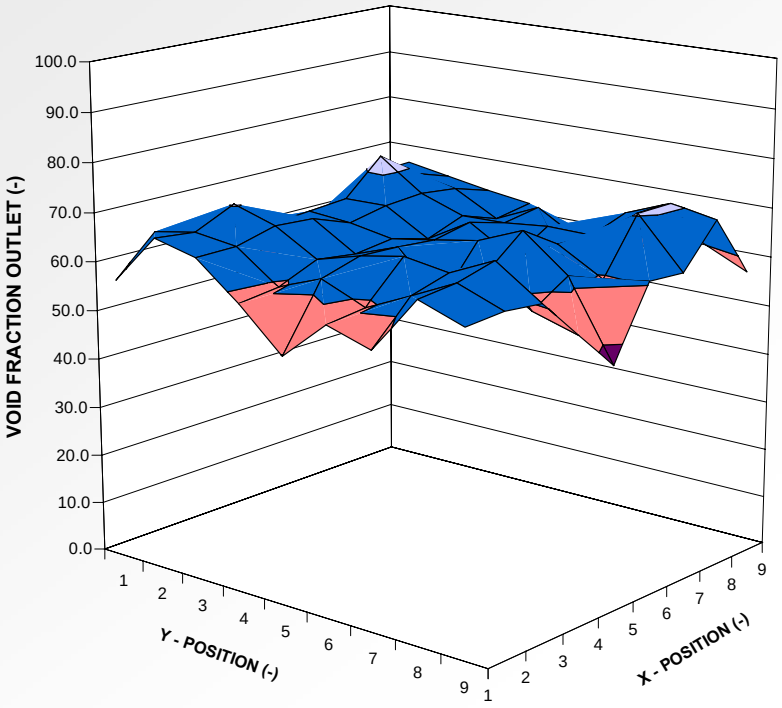
RESULTS: TEST 01-0011-58

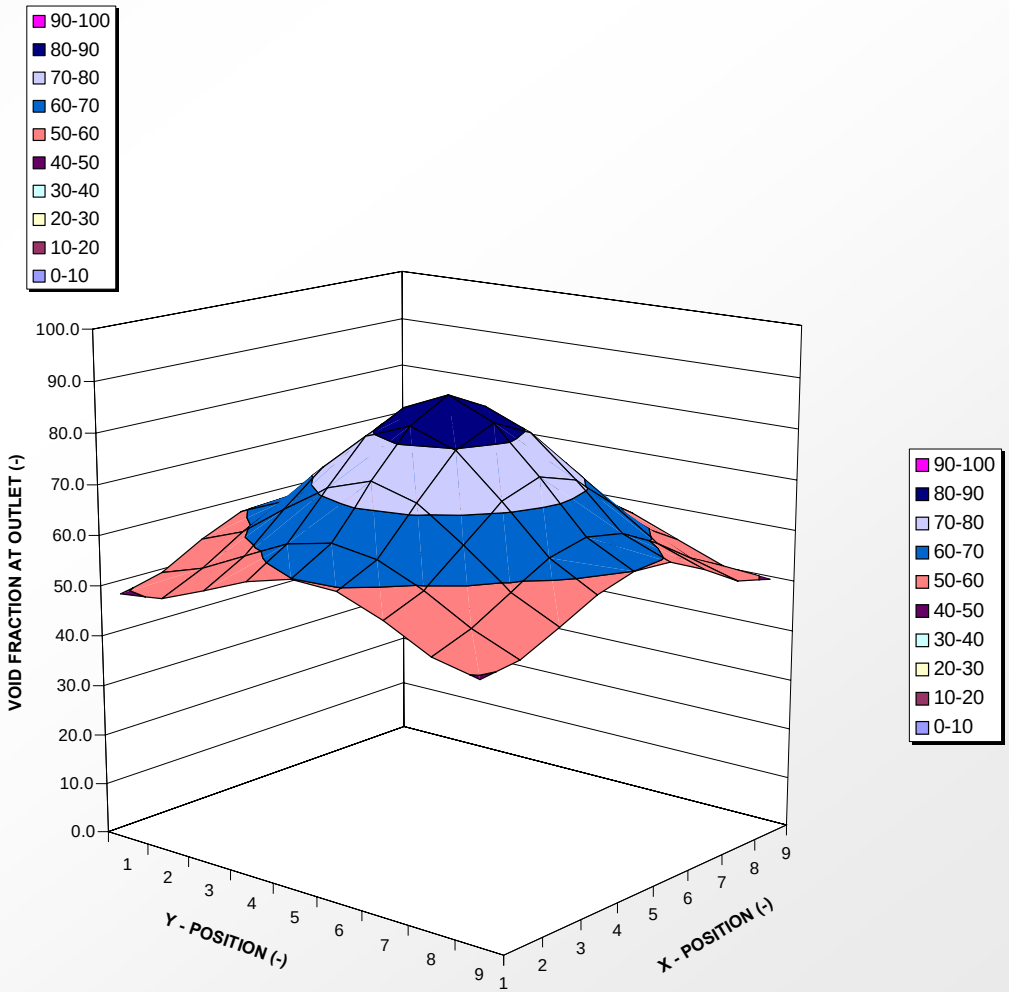
Void Distributions in all Channels



RESULTS: TEST 01-0011-58

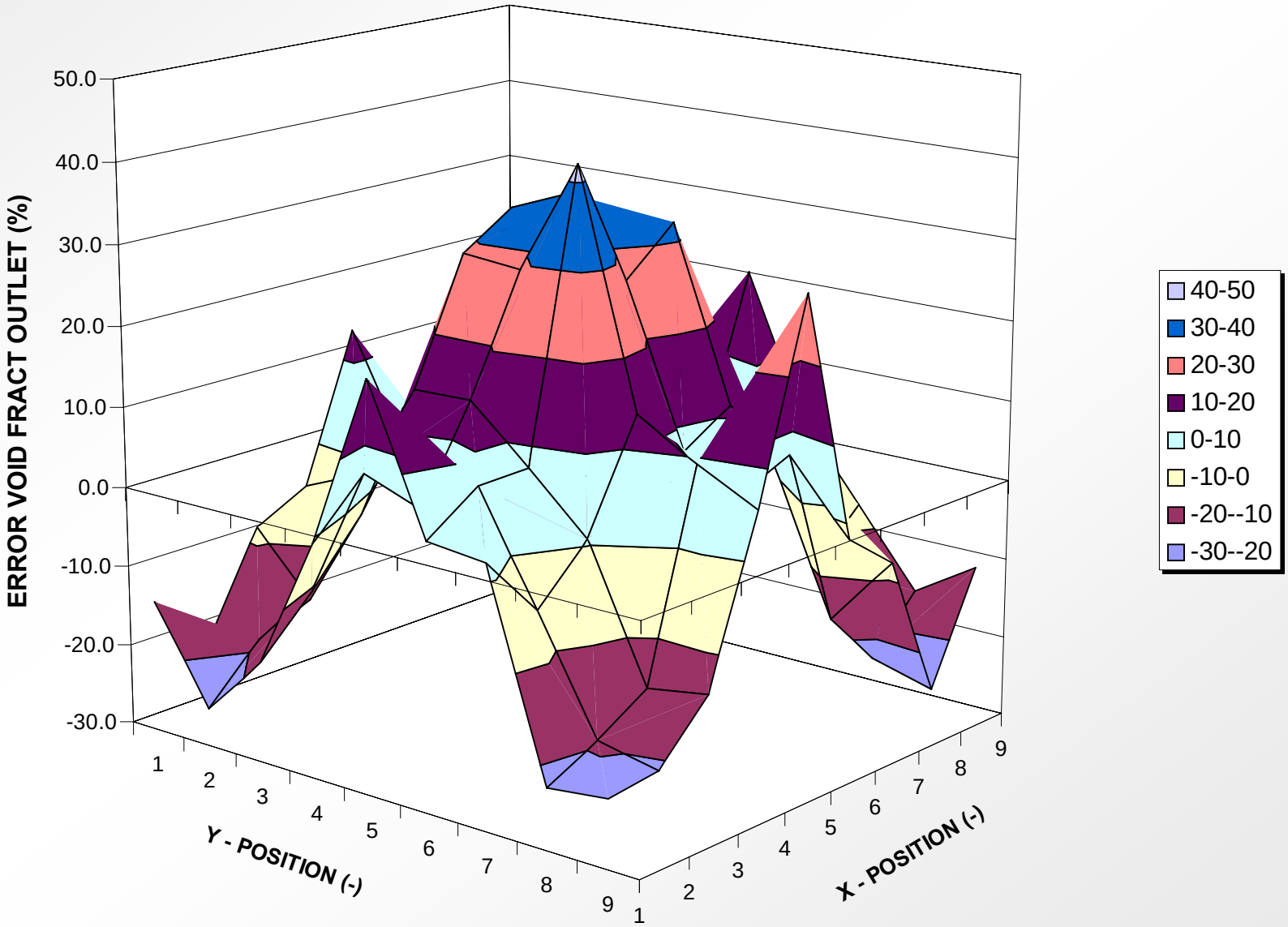
Measured and Calculated Void at Outlet





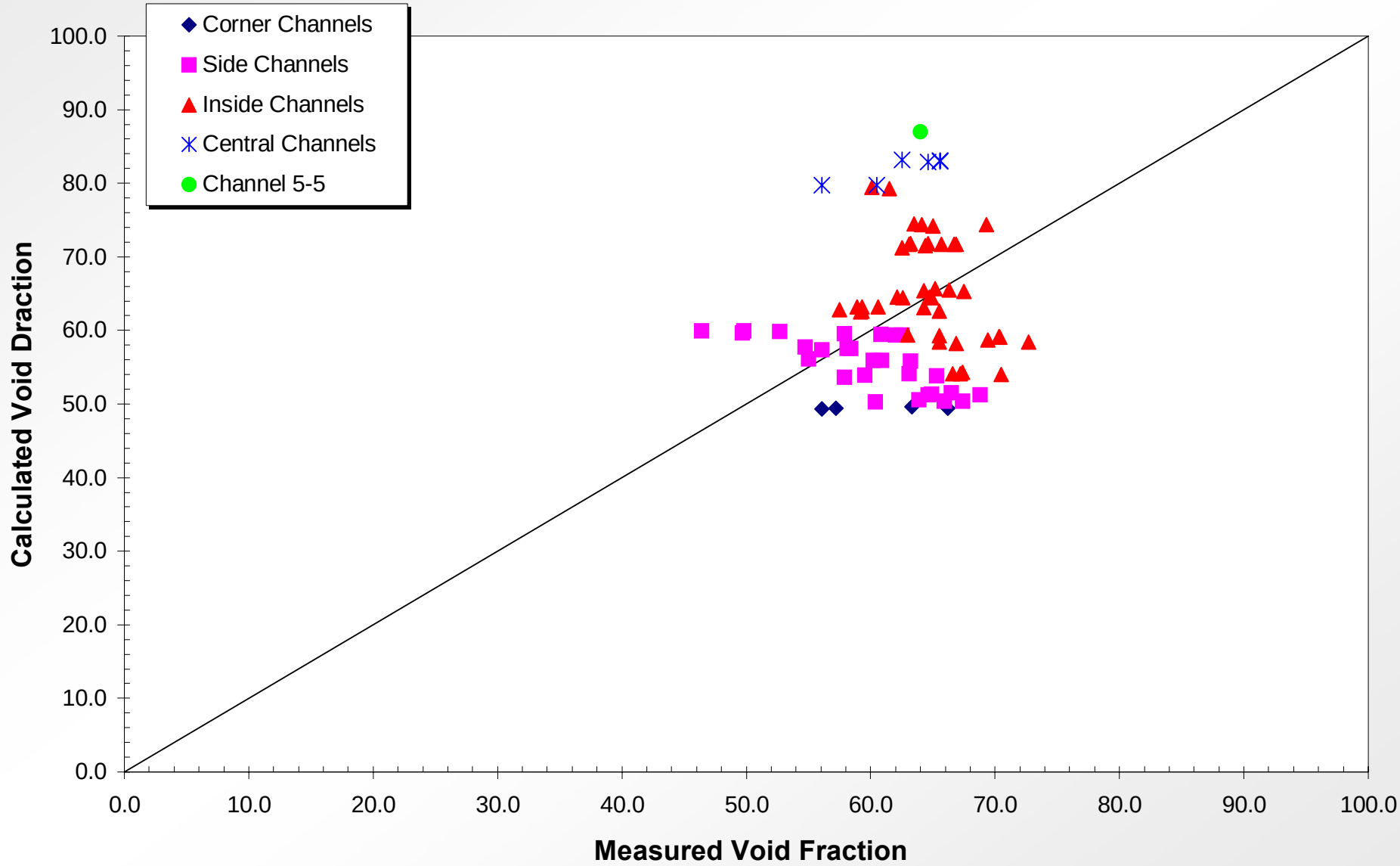
RESULTS: TEST 01-0011-58

Measured and Calculated Void at Outlet



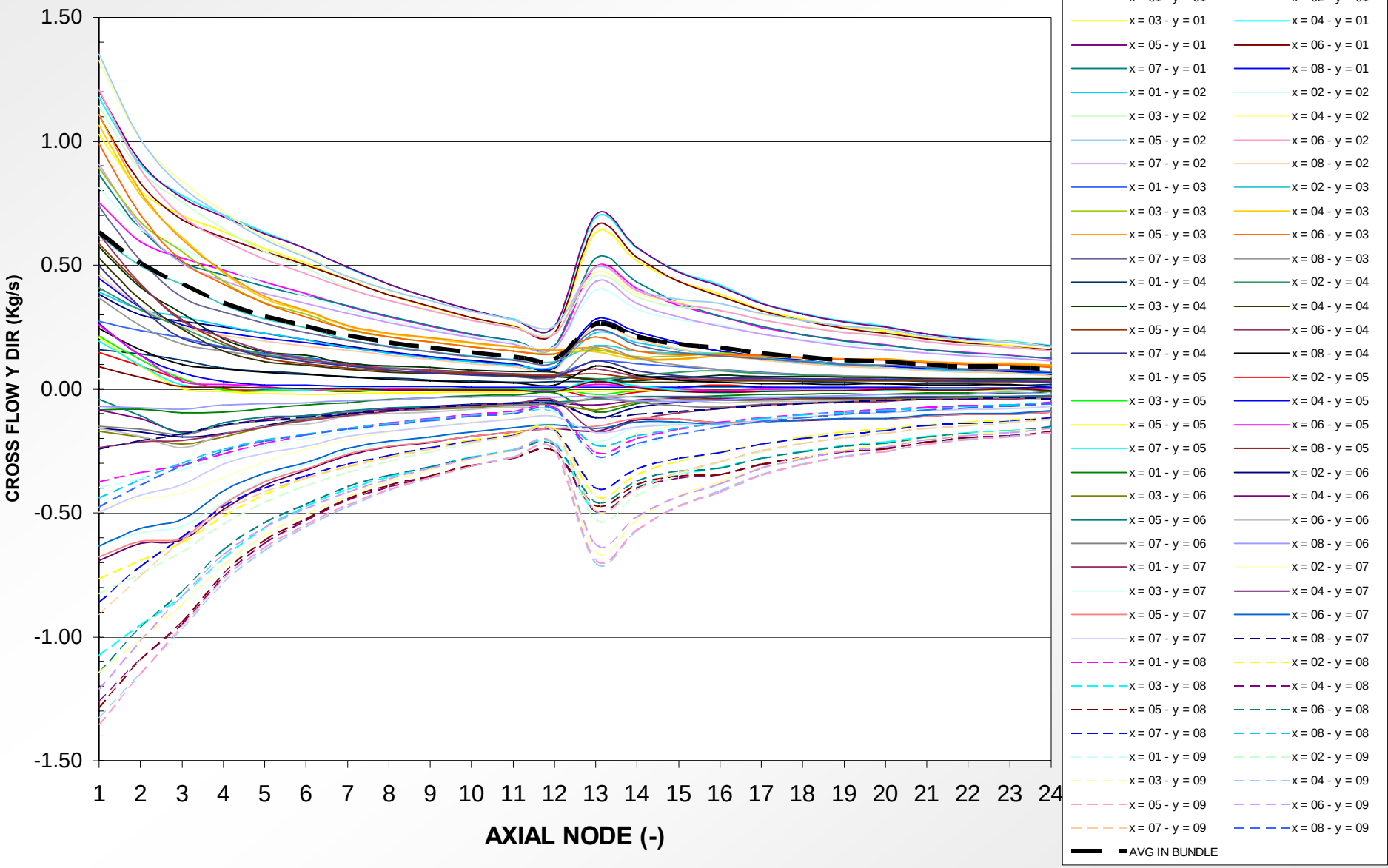
RESULTS: TEST 01-0011-58

Measured and Calculated Void at Outlet



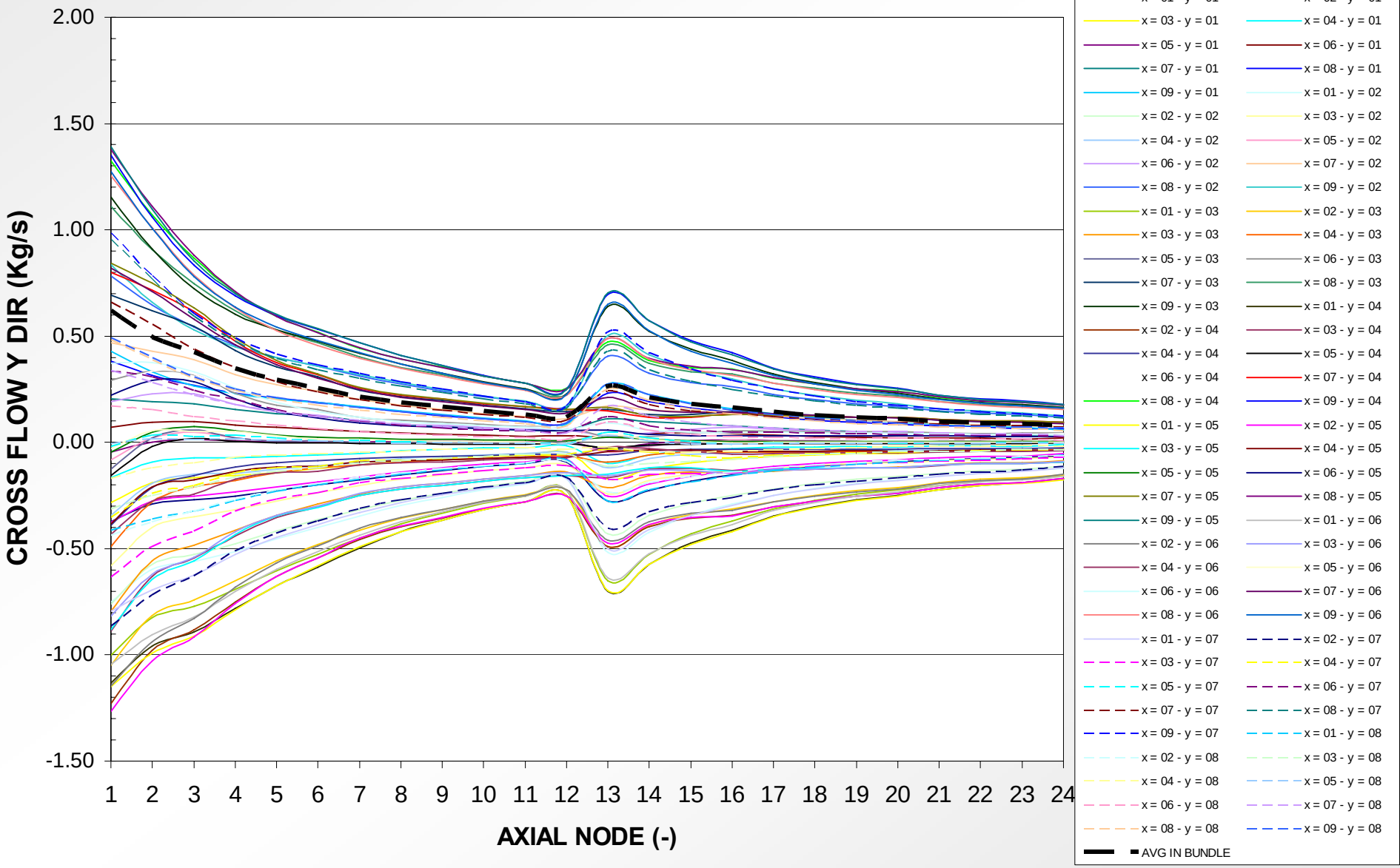
RESULTS: TEST 01-0011-58

Calculated Cross Flow Rate in x Direction



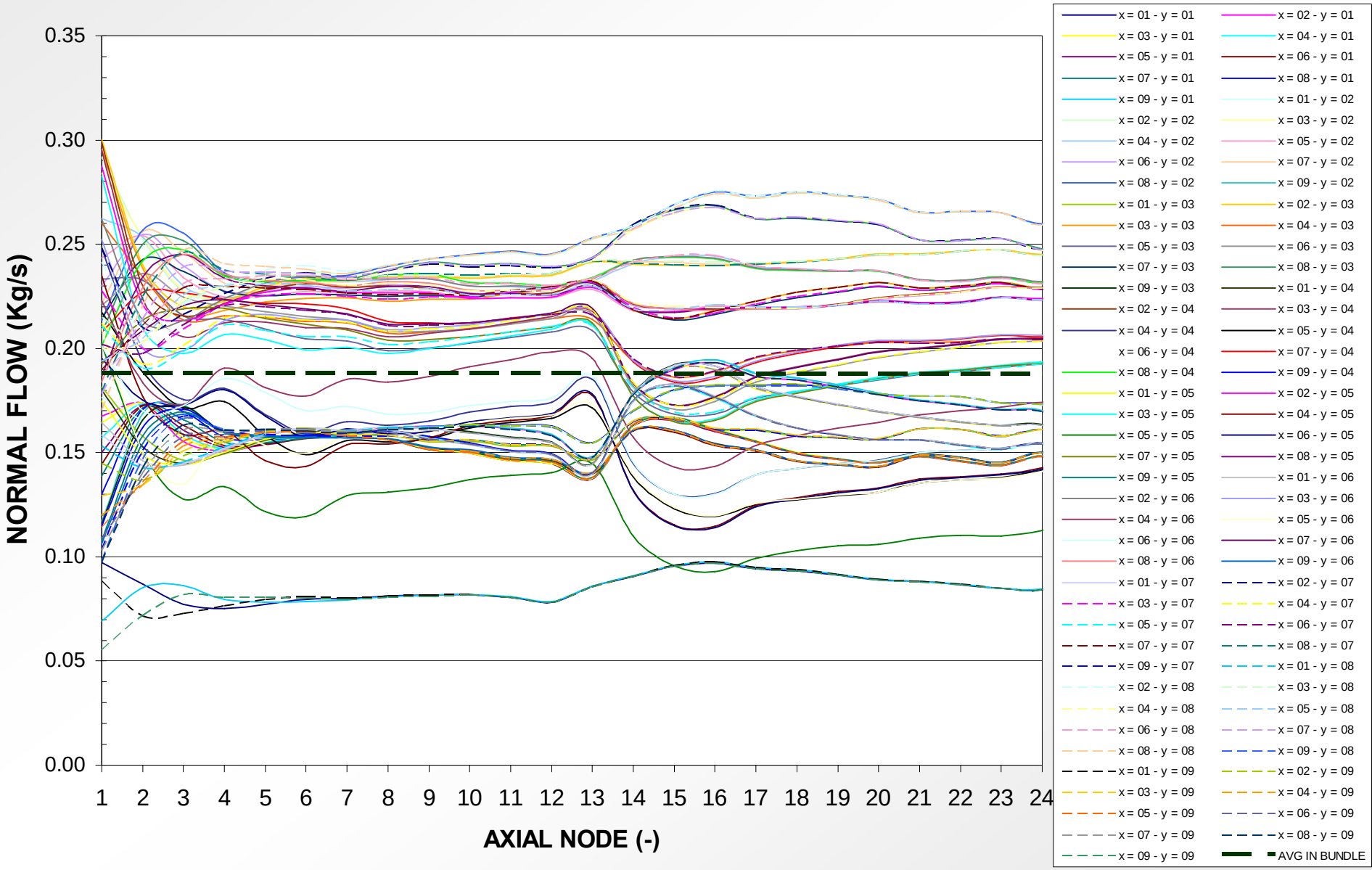
RESULTS: TEST 01-0011-58

Calculated Cross Flow Rate in y Direction



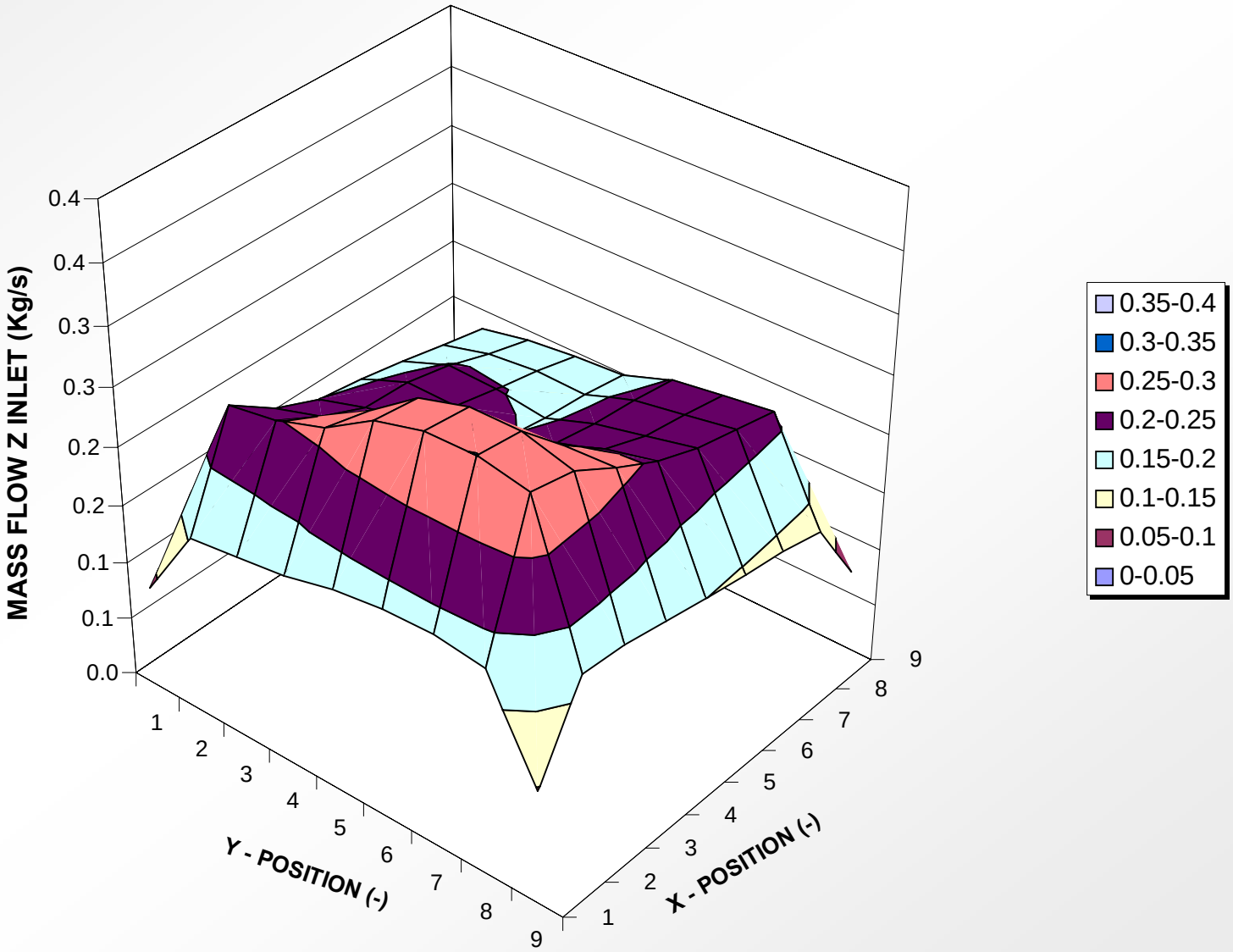
RESULTS: TEST 01-0011-58

Calculated Flow Rate in z Direction



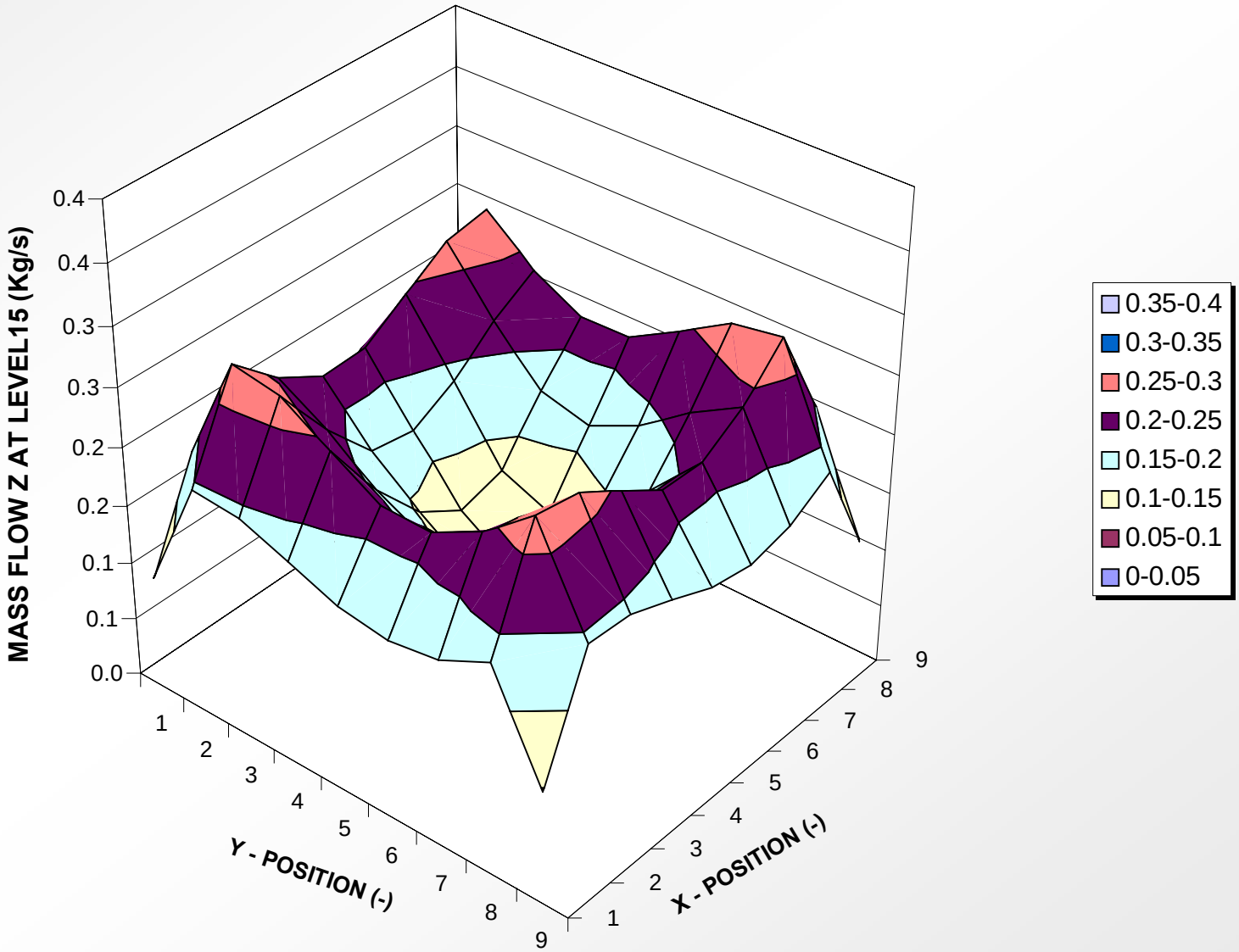
RESULTS: TEST 01-0011-58

Mass Flow Rate (z dir) Distribution at BAF



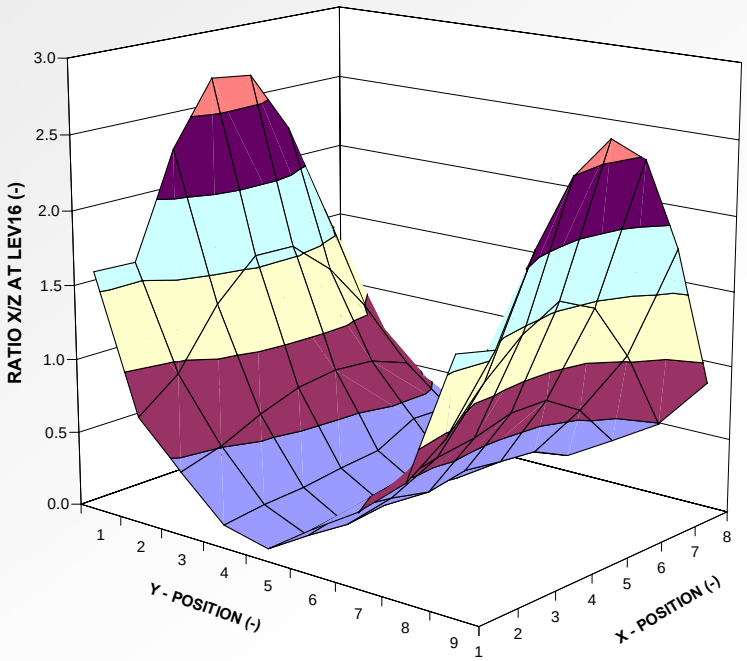
RESULTS: TEST 01-0011-58

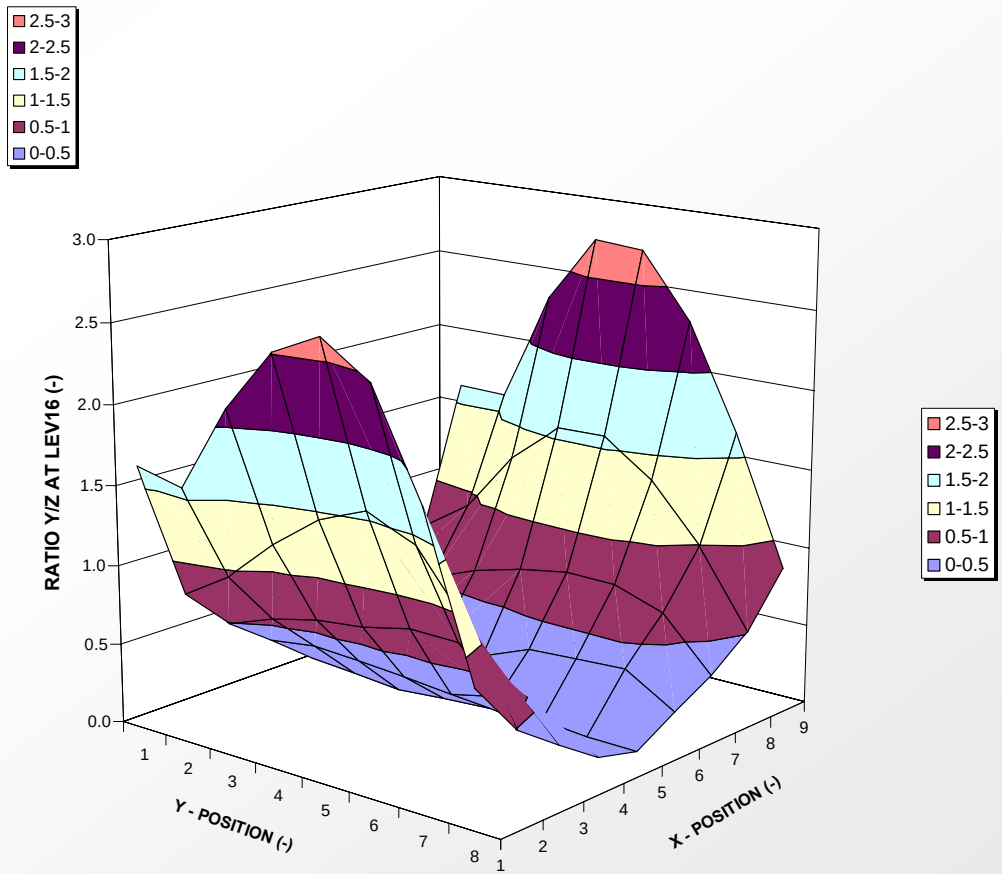
Mass Flow Rate (z dir) Distribution at TAF



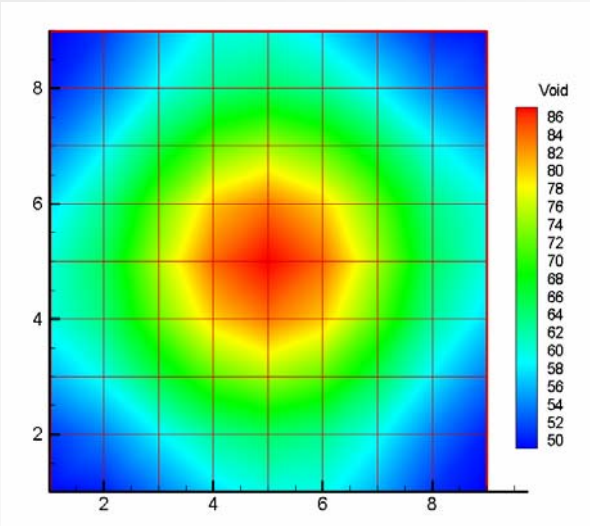
RESULTS: TEST 01-0011-58

Channel Cross Flow Rates (x & y) to Normal Flow Ratios

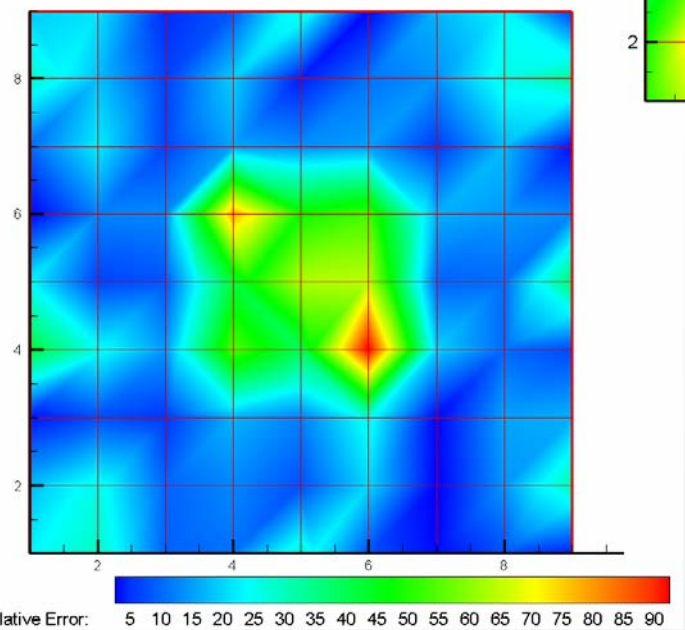


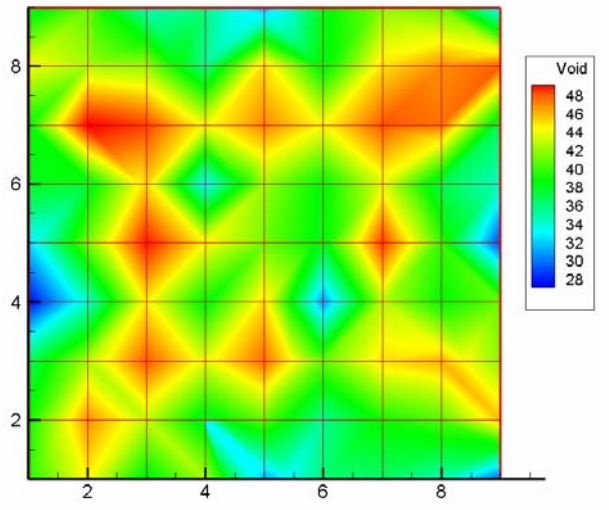


Results Test 01-0011-55 : VOID



CALC Void

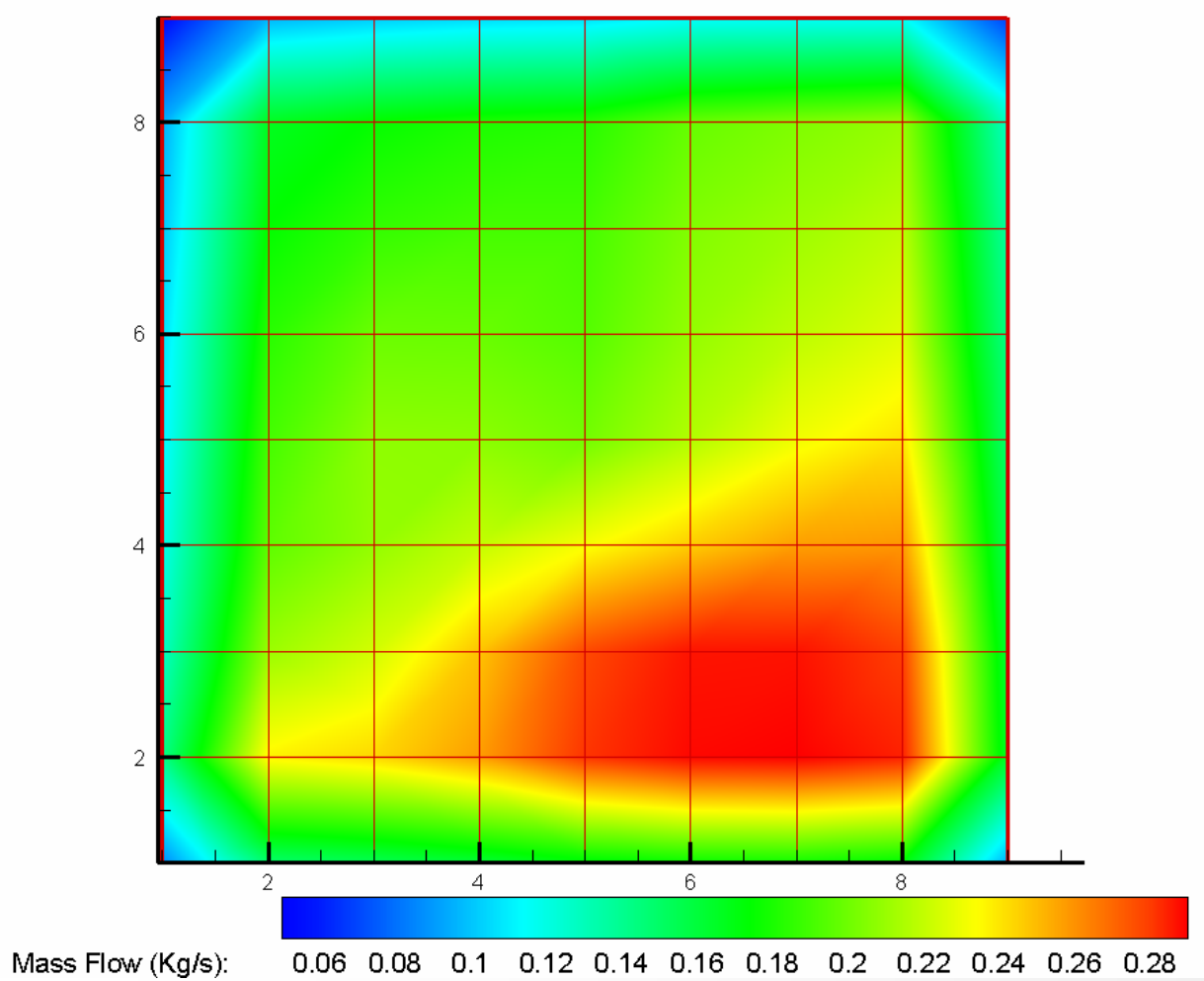




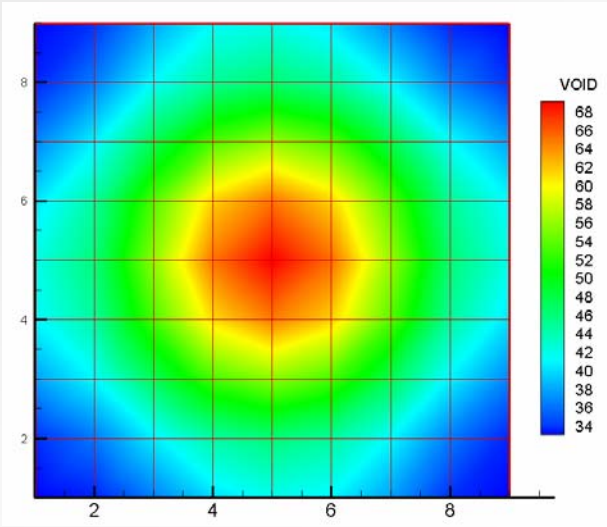
Exp Void

Avg Abs Error = 19.06

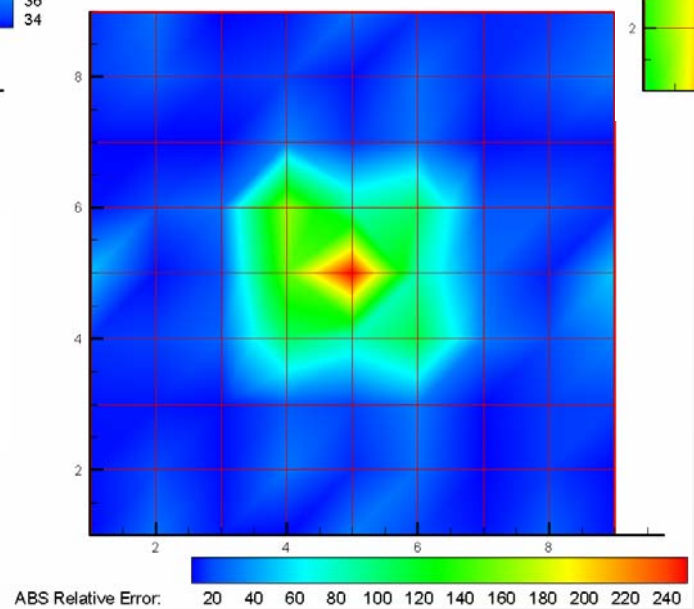
Results Test 01-0011-55 : Mass Flow Rate at BAF

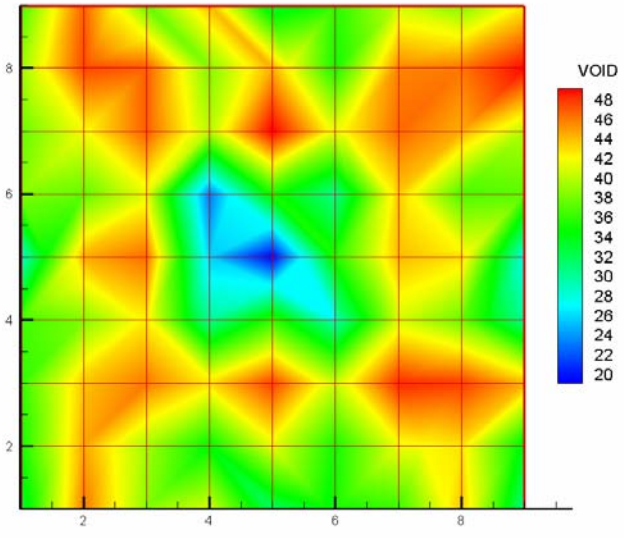


Results Test 02-0021-16 : VOID



CALC Void

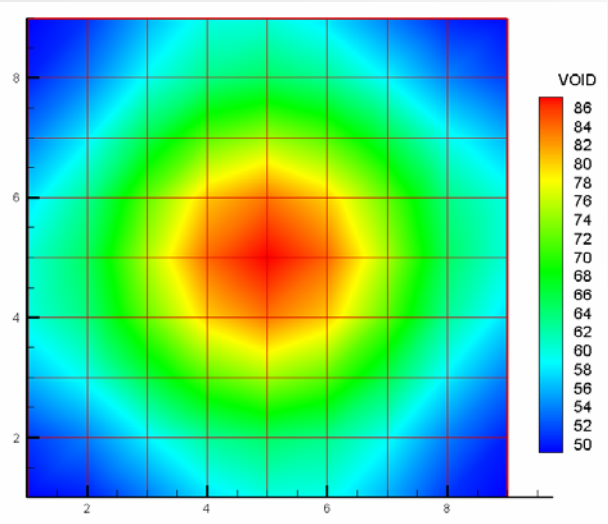




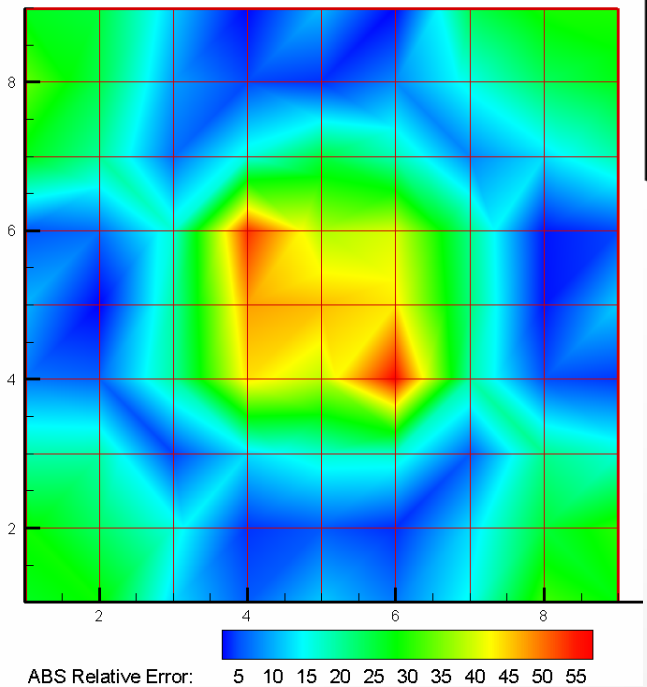
Exp Void

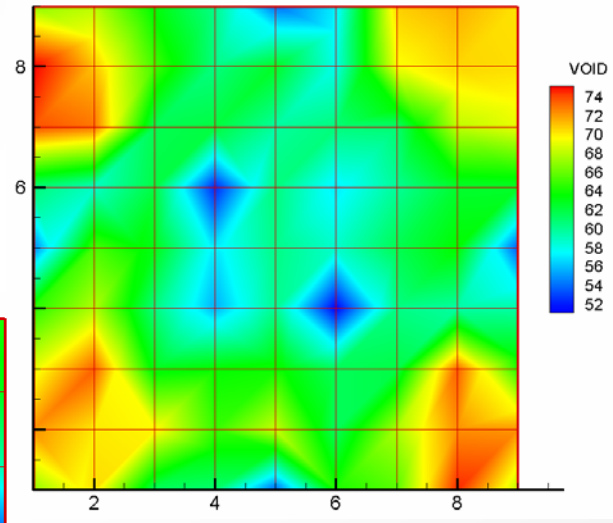
Avg Abs Error = 28.37

Results Test 1-1071-58 : VOID



CALC Void





Exp Void

Avg Relative Error = 18.56

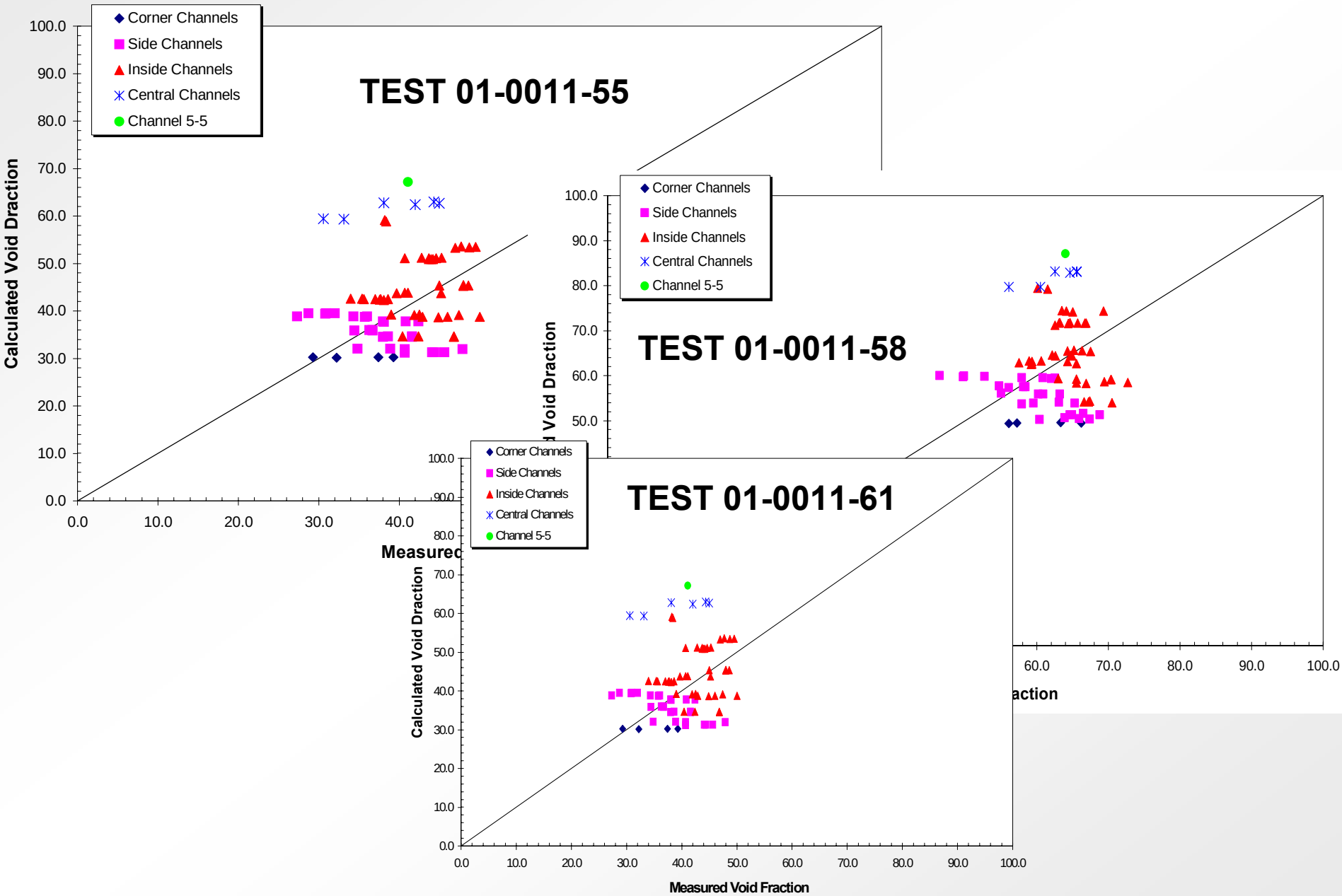
SUMMARY OF MAIN RESULTS: FA-0-1

TEST 0011-55				MAX		MIN	
	CALC	EXP	DIFF %	CALC	EXP	CALC	EXP
PRESSURE IN	7.20	7.21	-0.12				
PRESSURE OUT	7.15	7.15	0.00				
TEMP IN	552.07	551.65	0.08				
FLOW RATE IN	15.01	15.01	0.00				
LOCAL VOID OUT			19.61				
VOID OUT	42.51	40.35	5.37	67.18	50.00	30.18	27.30
DEN # 1	27.96	34.88	-19.83	43.80	41.80	13.39	23.70
DEN #2	13.81	4.08	238.57	22.39	6.40	6.40	2.50
DEN #2'	11.56	4.08	183.60	19.49	6.40	4.64	2.50
DEN #3	0.00	0.11	-100.00	0.00	1.00	0.00	0.00

TEST 0011-58				MAX		MIN	
	CALC	EXP	DIFF %	CALC	EXP	CALC	EXP
PRESSURE IN	7.20	7.22	-0.22				
PRESSURE OUT	7.14	7.14	0.03				
TEMP IN	551.27	551.25	0.37				
FLOW RATE IN	15.25	15.25	0.00				
LOCAL VOID OUT			13.67				
VOID OUT	62.59	62.67	-0.13	87.04	72.70	49.37	46.40
DEN # 1	51.71	65.48	-21.03	66.47	72.80	38.07	59.80
DEN #2	39.26	38.51	1.93	48.78	45.10	30.98	31.60
DEN #2'	35.87	38.51	-6.85	46.38	45.10	26.74	31.60
DEN #3	11.19	2.10	432.84	22.19	3.80	2.98	1.20

TEST 0011-55				MAX		MIN	
	CALC	EXP	DIFF %	CALC	EXP	CALC	EXP
PRESSURE IN	7.20	7.21	-0.12				
PRESSURE OUT	7.15	7.15	0.00				
TEMP IN	552.07	551.65	0.08				
FLOW RATE IN	15.01	15.01	0.00				
LOCAL VOID OUT			19.61				
VOID OUT	42.51	40.35	5.37	67.18	50.00	30.18	27.30
DEN # 1	27.96	34.88	-19.83	43.80	41.80	13.39	23.70
DEN #2	13.81	4.08	238.57	22.39	6.40	6.40	2.50
DEN #2'	11.56	4.08	183.60	19.49	6.40	4.64	2.50
DEN #3	0.00	0.11	-100.00	0.00	1.00	0.00	0.00

SUMMARY OF MAIN RESULTS: 0-1



SUMMARY OF MAIN RESULTS: FA-0-2

TEST 0021-16

	CALC	EXP	DIFF %	MAX CALC	MAX EXP	MIN CALC	MIN EXP
PRESSURE IN	7.21	7.22	-0.10				
PRESSURE OUT	7.16	7.16	0.00				
TEMP IN	551.72	551.55	0.39				
FLOW RATE IN	15.22	15.24	-0.09				
LOCAL VOID OUT			28.37				
VOID OUT	44.58	39.09	14.06	69.20	49.50	31.77	19.40
DEN # 1	31.16	33.36	-6.57	46.98	41.70	16.55	27.20
DEN #2	18.09	3.48	420.18	27.18	8.60	10.16	1.40
DEN #2'	15.69	3.48	351.14	24.67	8.60	7.72	1.40
DEN #3	1.45	0.16	834.14	3.79	0.40	0.20	0.00

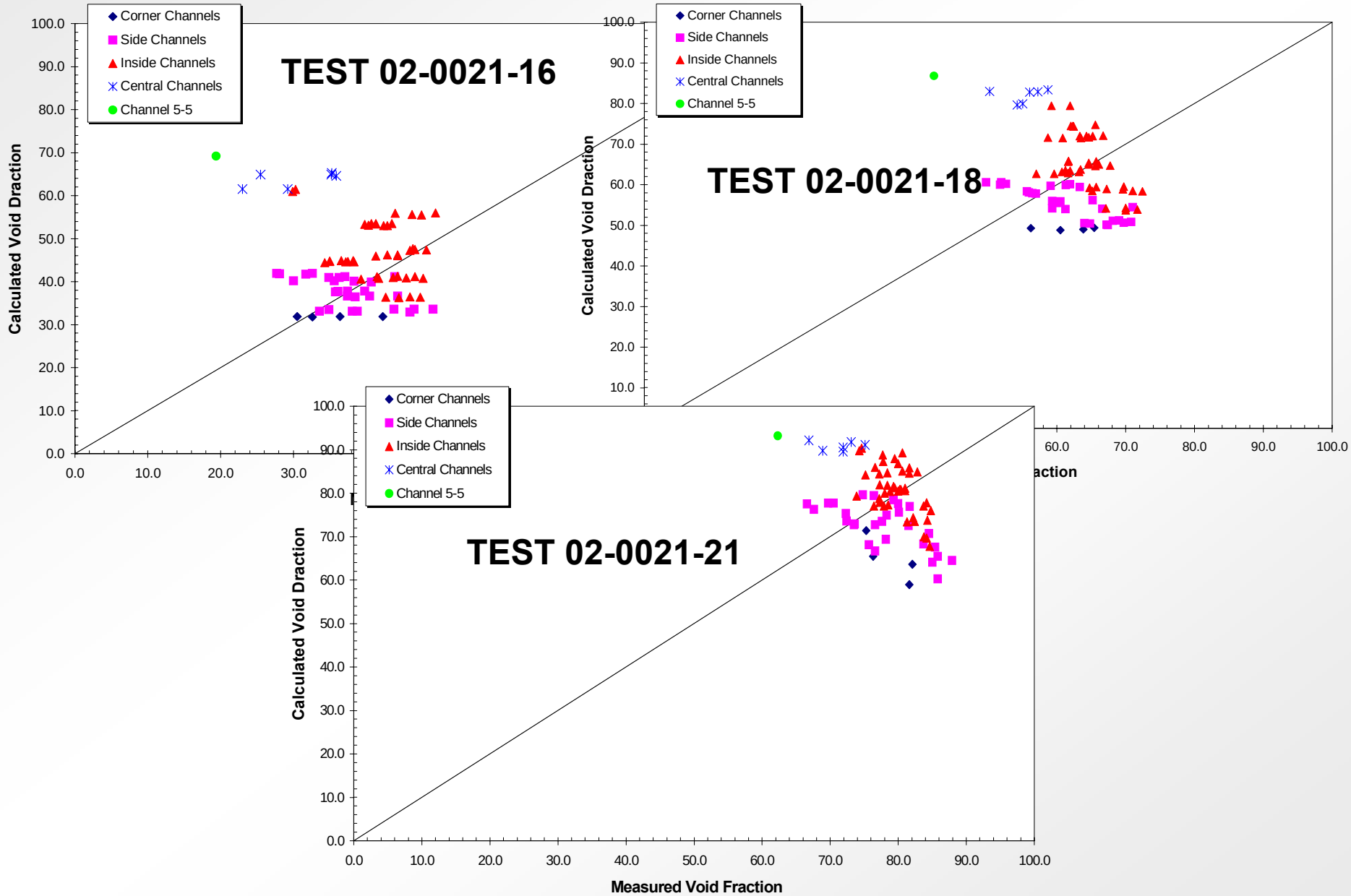
TEST 0021-18

	CALC	EXP	DIFF %	MAX CALC	MAX EXP	MIN CALC	MIN EXP
PRESSURE IN	7.19	7.21	-0.22				
PRESSURE OUT	7.13	7.13	0.03				
TEMP IN	551.39	551.35	0.37				
FLOW RATE IN	15.25	15.28	-0.18				
LOCAL VOID OUT			16.80				
VOID OUT	62.69	62.35	0.53	86.78	72.40	48.79	42.10
DEN # 1	51.97	63.81	-18.56	66.68	71.70	38.35	58.70
DEN #2	39.71	38.76	2.46	49.20	46.80	31.44	25.10
DEN #2'	36.37	38.76	-6.16	46.83	46.80	27.24	25.10
DEN #3	11.83	1.08	997.93	22.88	3.10	3.34	-0.50

TEST 02-0021-21

	CALC	EXP	DIFF %	MAX CALC	MAX EXP	MIN CALC	MIN EXP
PRESSURE IN	7.201	7.210	-0.121				
PRESSURE OUT	7.150	7.150	0.003				
TEMP IN	552.069	551.650	0.076				
FLOW RATE IN	15.008	15.008	0.001				
LOCAL VOID OUT			19.61				
VOID OUT	42.514	40.348	5.367	67.179	50.000	30.175	27.300
DEN # 1	27.962	34.878	-19.828	43.802	41.800	13.393	23.700
DEN #2	13.806	4.078	238.567	22.386	6.400	6.400	2.500
DEN #2'	11.565	4.078	183.599	19.488	6.400	4.641	2.500
DEN #3	0.000	0.111	-100.000	0.000	1.000	0.000	0.000

SUMMARY OF MAIN RESULTS: 0-2



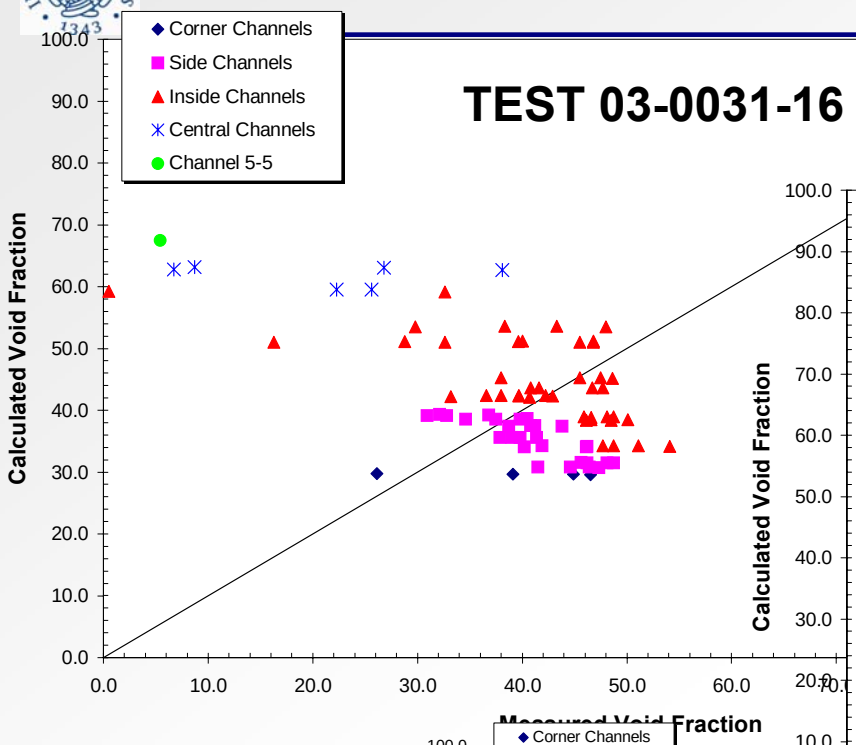
SUMMARY OF MAIN RESULTS: FA-0-3

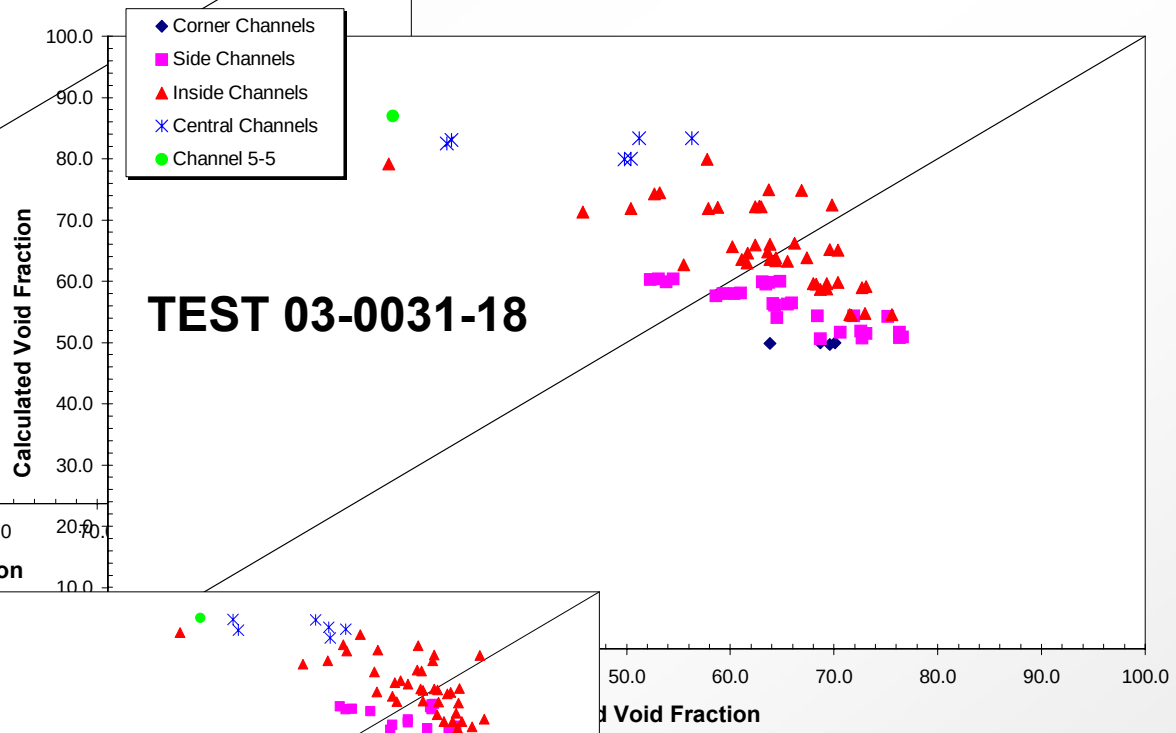
TEST 0031-16				MAX		MIN	
	CALC	EXP	DIFF %	CALC	EXP	CALC	EXP
PRESSURE IN	7.21	7.22	-0.11				
PRESSURE OUT	7.16	7.16	0.01				
TEMP IN	552.21	551.55	0.12				
FLOW RATE IN	15.25	15.27	-0.09				
VOID OUT	42.31	39.27	7.74	67.42	54.10	29.61	0.50
DEN # 1	27.88	34.92	-20.16	43.81	47.40	13.05	24.00
DEN #2	14.47	6.00	141.10	22.64	8.20	7.32	3.10
DEN #2'	12.33	6.00	105.49	19.85	8.20	5.68	3.10
DEN #3	0.08	0.43	-82.33	0.56	2.30	0.00	0.00

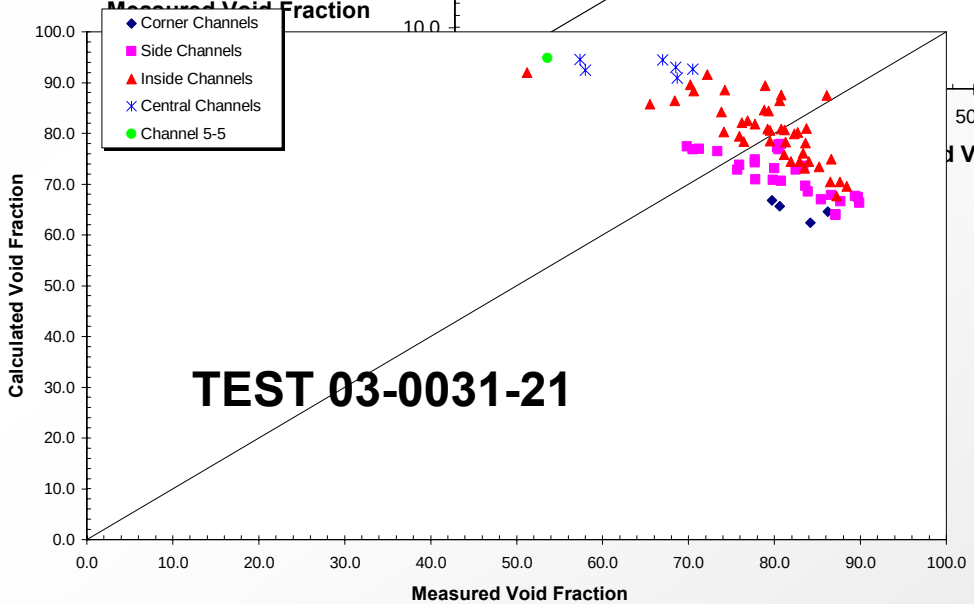
TEST 0031-18				MAX		MIN	
	CALC	EXP	DIFF %	CALC	EXP	CALC	EXP
PRESSURE IN	7.20	7.23	-0.38				
PRESSURE OUT	7.14	7.14	0.01				
TEMP IN	551.52	551.55	0.36				
FLOW RATE IN	15.22	15.22	0.00				
LOCAL VOID OUT			26.59				
GLOBAL VOID OUT	62.95	62.63	0.50	86.99	76.60	49.63	27.10
DEN # 1	52.19	63.32	-17.58	66.82	73.80	38.60	46.60
DEN #2	40.10	39.89	0.54	49.49	51.80	31.82	24.00
DEN #2'	36.81	39.89	-7.71	47.15	51.80	27.67	24.00
DEN #3	12.69	2.21	473.88	23.71	4.00	3.97	0.80

TEST 0031-21				MAX		MIN	
	CALC	EXP	DIFF %	CALC	EXP	CALC	EXP
PRESSURE IN	7.21	7.25	-0.58				
PRESSURE OUT	7.13	7.12	0.10				
TEMP IN	552.25	551.20	0.55				
FLOW RATE IN	15.25	15.28	-0.19				
LOCAL VOID OUT			16.14				
VOID OUT	77.90	78.55	-0.83	94.84	89.90	62.40	51.20
DEN # 1	70.07	79.22	-11.56	80.19	86.70	55.58	66.60
DEN #2	60.64	60.91	-0.44	70.07	72.40	52.02	40.20
DEN #2'	57.84	60.91	-5.05	68.17	72.40	48.33	40.20
DEN #3	30.50	25.00	21.98	46.06	34.10	14.85	17.40

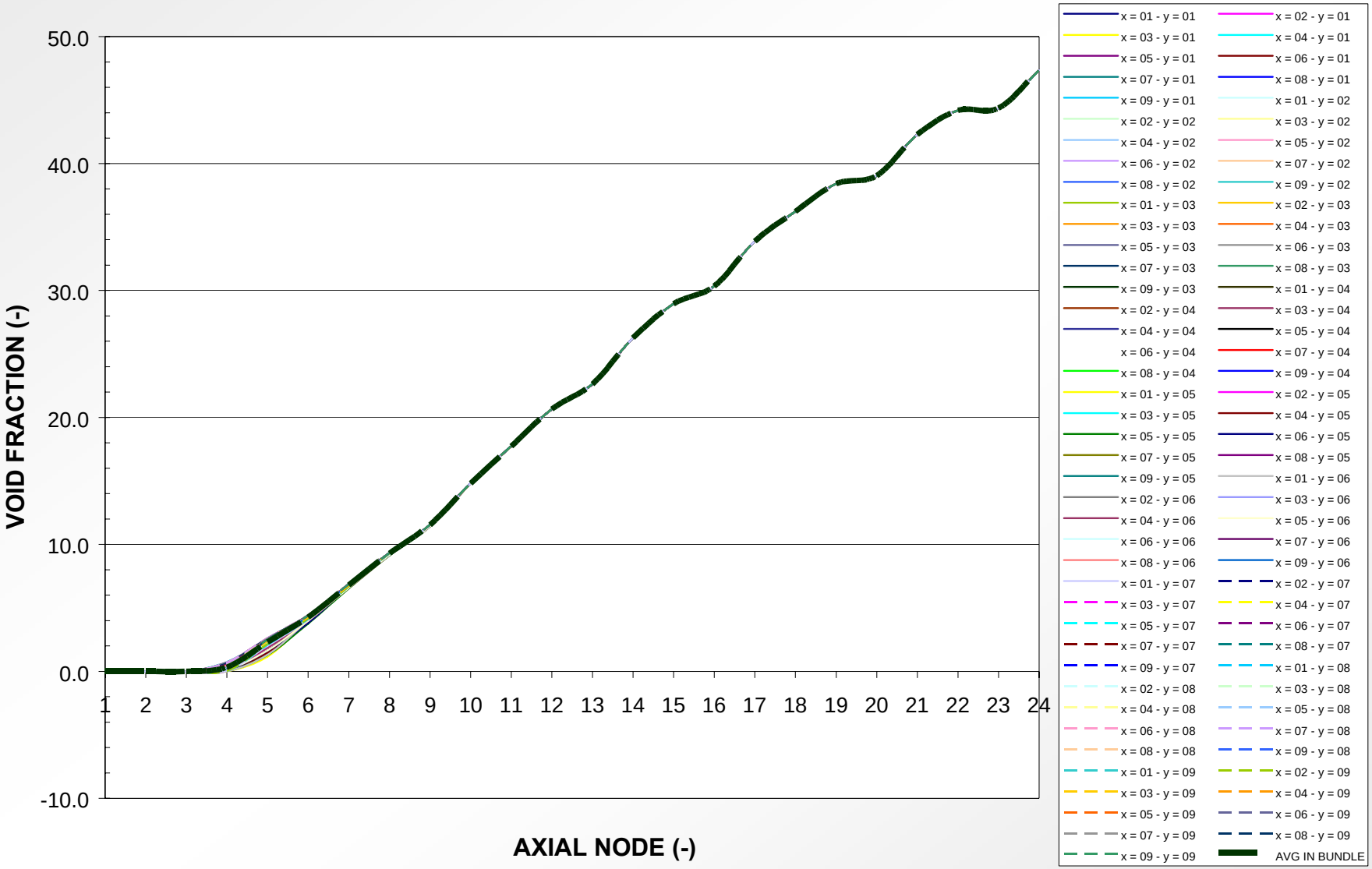
SUMMARY OF MAIN RESULTS: 0-3



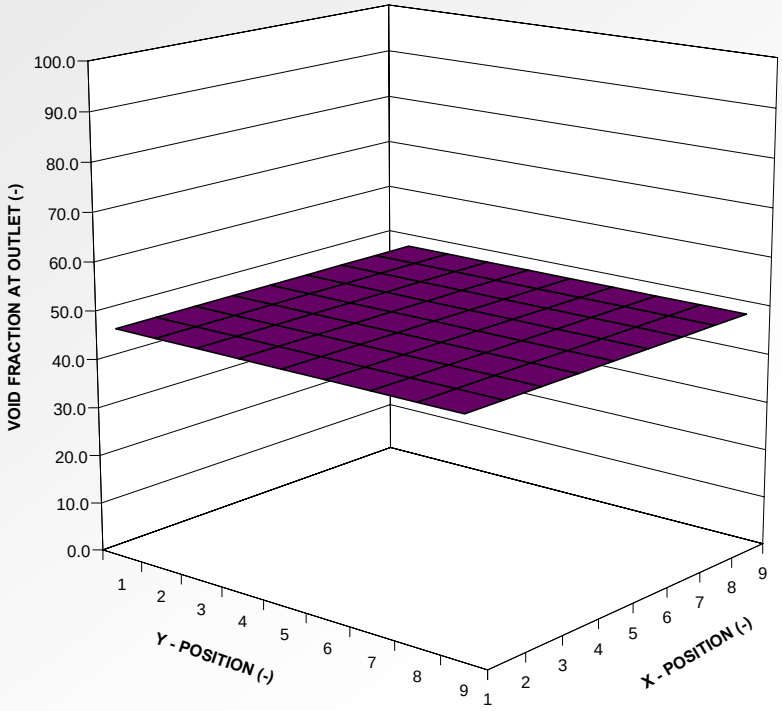


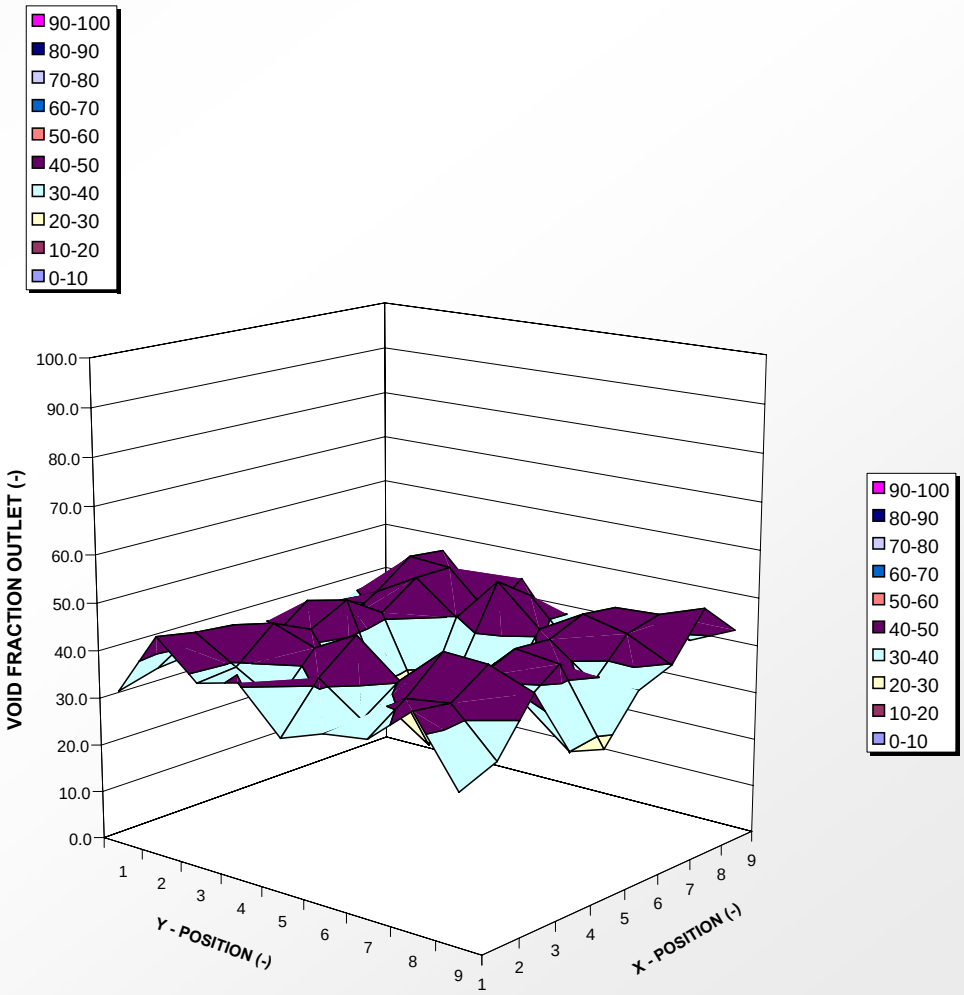


Sensitivity: Test 0021-16, 1D Momentum & w. rod

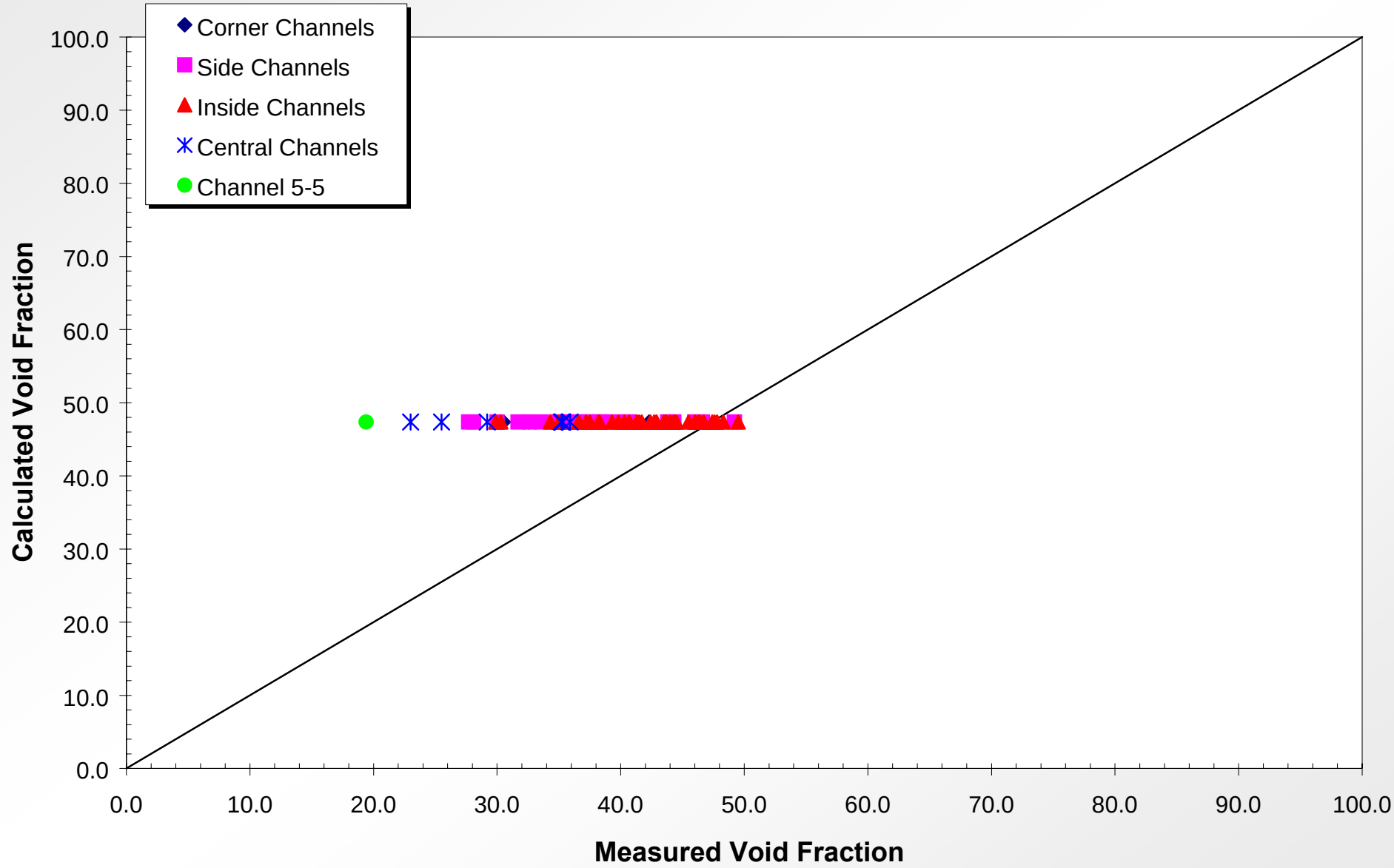


Sensitivity: Test 0021-16, 1D Momentum & w. rod





Sensitivity: Test 0021-16, 1D Momentum & w. rod



CONCLUSIONS AND FUTURE WORK

- The use of a RELAP5-3D System code in the subchannel approach has been presented
- The code is able to predict with high accuracy quantities at 'bundle' level: Pressure Drops, Void at Outlet.
- At 'subchannel' level, the accuracy of the prediction void distribution prediction is about 20%
- The accuracy is improving for tests with high quality (for the same reason the agreement is better at TAF, and worst at the axial position where the densitometers are located)
- **Future work:**
  - Re-analysis of the performed calculations (all calculation were preliminary)
  - To run the test NOT still performed, in particularly Transient tests
  - The huge experimental database available, may allow to Assess the CIAU capability for Uncertainty Evaluation of Calculated results using RELAP5-3D as subchannel code