BALANCING LOW NOx BURNER AIR FLOWS THROUGH THE USE OF INDIVIDUAL BURNER AIRFLOW MONITORS

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Background

In response to the 1990 Clean Air Act Amendments and the subsequent NOx compliance rules, utilities have been retrofitting low NOx firing systems on their existing fossil fired boilers. For the majority of these units which were built prior to the implementation of the New Source Performance Standards (NSPS), the original burner designs were intentionally turbulent and encouraged rapid mixing between the combustion air and fuel streams both for individual burners and between adjacent burners flows. Under these operating design parameters it was not particularly critical that the fuel and combustion air flow balance between burners be measured, controlled or maintained since satisfactory mixing was quickly achieved within the combustion zone.

Most if not all of the commercial low NOx burner systems, with an emphasis on those for wall and down fired boilers, were initially designed, developed and tested either in single burner test facilities or through the use of computational fluid dynamic (CFD) modeling. In either case the ability to control design sensitive flow ratios, the fluid dynamics and, hence, the combustion process was well maintained. Thus, either through testing in a single burner test facility or theoretically through CFD modeling, the burners were optimized in an attempt to provide the most competitive design, both in terms of cost and performance. The resultant products, more often than not, have incorporated multiple dynamic control devices per burner, such as shrouds or discs to regulate flow and registers or vanes to control zonal flow proportions and swirl. However, all of these variables and there control devices are interdependent. Therefor, as firing systems are expanded beyond a single burner configuration, the ability to operate the equipment under the optimal design conditions becomes increasingly more difficult. In reality, the deviations between the field and design conditions can produce such varied dynamic conditions between burners that the operational and performance sensitivities experienced in the single burner facility and through CFD modeling become difficult to measure. No longer can one variable be changed uniformly amongst all the burners to measure its impact, in part, because it also impacts the other dependent variables but mostly because the system does not start with a balanced set of conditions between burners. Some field experiences have shown that the low NOx systems, once installed, have experienced less than desirable sensitivity to optimization efforts. The burner conditions are so difficult to balance that the combustion process is too muddy to differentiate change and readily achieve improvements.

While limitations in reproducing design conditions in the field applications of low NOx systems may not be a significant issue for some utilities in meeting Title IV NOx compliance, future rule considerations which will likely force the utilization of post combustion ammonia based technologies will significantly add economic benefit to the ability to achieve and maintain true NOx emission optimization on the combustion side through potentially SCR or SNCR capital and reagent cost avoidance. This paper discusses the development and application of at least one control component, individual burner air flow monitors, IBAMs,` to assist in the balance and optimization of low NOx combustion systems.

AMC Power Flow Technology

The flow measuring technology used for the IBAMs is based upon AMC Power's VOLU-probe design (U.S. Patent 4,559,835). The VOLU-probe is a multiple point, self-averaging pitot tube requiring very little straight duct run to maintain an accurate flow signal. The VOLU-probe operates on a Fechheimer pitot derivative of the multi-point, self-averaging pitot principle to measure the total and static pressure components of airflow. Total pressure sensing ports, with chamfered entrances to greatly lessen entrance effects, are located on the leading surface of the VOLU-probe to sense the impact pressure (Pt) of the approaching air stream (Figure 1). Fechheimer static pressure sensing ports, positioned at designated angles offset from the flow normal vector, minimize the error-inducing effect of directional, non-normal airflow. As the flow direction veers from normal (Figure 2), one static sensor is exposed to a higher pressure (Ps + part of Pt) while the other is exposed to a lower pressure (Ps - part of Pt). For angular flow where $\alpha = \pm 30$ degrees offset from normal, these pressures are offsetting and the pressure sensed is the true static pressure. It is this unique design of the offset static pressure and the chamfered total pressure sensors (Figures 1 & 2) that make the VOLU-probe (and IBAM) relatively insensitive to approaching multi-directional, rotating airflow with yaw and pitch of up to 30 degrees from normal, thereby assuring the accurate measurement of the sensed airflow rate without the presence of upstream airflow staighteners.

Development

American Electric Power's Muskingum River 5, a 600 MW supercritical, pulverized coal fired unit with cell burners, was retrofit in 1993 with DB Riley's CCV low NOx burners (reference Figure 3). At the time, a DB Riley standard for the CCV included the use of a Brandt single point shrouded air flow probe located just inside the register. In such a turbulent and non-uniform flow environment, this application produced very poor results and offered no value in the balancing of secondary air flows between the 50 burners on this unit. With AEP having already successfully applied Air Monitor Corporation's VOLU-probe technology to a roof-fired unit for dynamic per burner stoichiometric air flow control, AEP, DB Riley and AMC worked together to apply the technology to a sampling of 3 of the CCV burners at Muskingum River 5 (reference Figure 4).

Because this application had oil lighter guide tubes in the secondary air annulus, the VOLU-probes were installed in four quadrants of the burner barrel as shown in Figure 5. Each probe was independently used to characterize the secondary air flow for each of the three outfitted burners. The purpose of this test array was to evaluate the effects of flow variations within a common wind box and the impact of measuring flow in the shadow or downstream of the ignitor guide tube. All 3 burners selected are of the same flow rotation and located at the far left, right and center of the wind box and at the same elevation in an attempt to assure the same wind box to furnace differential. Each probe was also rotated 15 degrees into the direction of flow rotation to improve its sensitivity and the flow indication then corrected by a factor of cosine of 15 degrees. The results of this testing are illustrated in Figure 6 and were very favorable. While the flow disruption created by the ignitor guide tube did result in a deviation from the mean for one of the 3 burners tested (burner 4D Lower, probe positions C and D) the others and, in particular, those upstream of this upset showed very consistent values. In addition this testing was repeated after a period of six months of operation with repeated results and no routine attention to the probes between the tests. While AEP has yet to outfit the balance of the Muskingum River 5 burners with VOLU-probes, the balance of AEP's low NOx burner retrofits (>500 burners) utilizing the DB Riley CCV burner design are standardizing on the use of two VOLU-probes per burner. The selection of two probes is to provide both averaging for accuracy and redundancy for troubleshooting (i.e. individual probe pluggage) as they are headered external to the wind box.

AEP has also developed their own patented low NOx burner technology applicable to its roof fired boilers in which the AMC VOLU-probe technology is being used to measure and control individual burner stoichiometries on a real-time basis based upon indicated pulverizer coal throughputs. Since these units only have two burners associated with each pulverizer, fuel distribution issues are reasonably manageable and balance between coal conduits is assumed in the controls. The result has been better air flow distribution on the units, better excess air balance without operator interface, and, after application to five units with up to three years of operation, there has been no degradation in the system's NOx emissions control capability.

The success of both applications mentioned above also prompted AEP to apply VOLU-probes to the outer secondary air zone of previously retrofitted, FWEC designed, dual register, IFS low NOx burners. The secondary air flow measurement supplied by FWEC with the burner was found to be greatly inadequate for the purpose of balancing air flows on the unit (800 MW supercritical with 18 IFS burners on both the front and rear walls). While by design the outer secondary air zone flows with these burners are only intended to represent about 60% of the total combustion air to each burner the VOLU-probes were found to significantly help in improving overall unit air flow balance as indicated by economizer gas sampling grid analysis and the unit's excess air probe indications. The limitation of measuring only the major of a total of 3 secondary air flow streams on this burner design coupled with difficulties in long term repeatable register adjustments does not allow this application to present much hope of dynamic burner air flow balancing and control. This application did assist though with achieving an additional 10% increment (0.05 lbm/MBtu) of full load NOx emission reductions on the unit to which it was applied.

Although AEP had developed confidence in the VOLU-probe technology, there remained some detractors to its absolute accuracy, particularly when applied to a circular burner's secondary air annulus. So in October of 1997 testing was performed using one of the DB Riley CCV low NOx burner registers fabricated for AEP's Big Sandy Unit 1 in AMC Power's wind tunnel. The primary purpose of the testing was to evaluate the absolute accuracy of the AM Power individual burner air monitor (IBAM) equipment in this turbulent, non-uniform flow field application with the benefit of ASME flow nozzles for comparison. The results of this testing were evaluated independently by AMC Power (AMC), DB Riley (DBR) and AEPSC. A copy of the AMC and DBR reports can be requested directly from these sources. A summary of AEP's own analysis is summarized below.

CCV Low NOx Burners

For the benefit of those unfamiliar with the CCV low NOx burner, it is the only commercial low NOx burner that, without the use of overfire air, was standardized with a single register configuration in the control of NOx emissions. This is effective because of both the nozzle technology and the secondary air divertor at the end of the coal nozzle. The secondary air divertor acts as a bluff body to help achieve good flame attachment and provides enough secondary air separation to achieve the internal combustion air staging commonly associated with a more complex dual-register low NOx burner. From a practical and operational standpoint, the reduced complexity reduces initial capital investment and maintenance costs and eases optimization efforts. With the optimization of a low NOx system, it is crucial that the dynamic combustion conditions at all in-service burners be as balanced as feasible in order to be able to measure the sensitivity of emissions to the available control parameters. A starting point is to achieve the best possible balance across a unit between coal, primary air and secondary air flows for each burner.

While it is anticipated that the primary air and coal balance is currently less than desirable, we are able to perform periodic calibration checks to assure than the mills are operated consistently, and the burner conduits have been orificed to theoretically balance the coal conduit pressure drops. However, all of the theory work has assumed a homogeneous air/fuel mixture exiting the mill classifiers. There are R&D efforts ongoing within EPRI, Lehigh University and other organizations to develop the ability to dynamically measure the actual “real time” coal conduit flow distributions.

Testing and Results

Representatives of AMC, DBR and AEPSC participated in the wind tunnel testing with the IBAM in the Big Sandy 1 CCV burner register. Matrices of tests were developed to test the accuracy of the IBAM under a range of register conditions and flows. In the range of normal average Big Sandy 1 full-load per-burner flows (in cfm) and 50% of this flow, the register settings were adjusted in 5-degree increments from 20 to 35 degrees open and with shroud positions of 30, 50, 70 and 100% open. In addition, several sensitivities involving IBAM probe positions and orientations to flow direction were investigated. The base case orientation of the IBAM probes (reference Figure 7) was 24” downstream of the CCV register front plate, individually turned 15 degrees into the direction of flow rotation (Figure 7) and 90 and 225 degrees upstream (rotationally) from the oil lighter guide tube. This is consistent with the orientations previously planned for all of the future AEP CCV burner retrofits. The other probe position variations included moving the probes 12” closer to the register front plate and changing the effective individual burner probe rotation from 15 degrees from axial to 5, 10, 20, 25, 30 and 35 degrees from axial. Again the purpose of rotating the individual probes is to attempt to sense the maximum (total) velocity head (Figure 8). To correct this back to an axial flow, we have used a correction factor of the cosine of the probe rotational angle. A series of tests was also performed without the oil lighter guide tube to assure that the accuracy with its inclusion was not affected with the selected probe orientations.

With the test cases of moving the probe axially to 12” from the register front plate and rotating the probes to 5 degrees from axial, the errors in the probe flow measurements became significant, with an total error band of 26-30% (reference Figures 9). For the balance of the test conditions, the error bands were generally less than 15% (Figure 10). These results suggest that the cosine correction is reasonable, but as also observed during the testing, the radial gradients in the amount of flow swirl was significant, and although not measured during these tests, the radial total flow gradients may also be significantly skewed and contributing to the levels of error measured.

After this testing was complete, portions of the data were randomly applied to a neural network to then develop a model for predicting the true flow more accurately. Incorporated as inputs to the neural network model were shroud position, register position and the raw IBAM flow indication. The result was the ability to reduce the margin of error to within 1%. The potential, therefore, exists to use either the cosine correction plus a fixed error bias value or the neural network modeled correlation to implement real time and reasonably accurate per burner flow measurement and respond with improved real time per burner flow control and balance.

Additional Wind Tunnel and Field Testing

Subsequent wind tunnel testing has been performed with IBAMs in another CCV burner register that is of a different size and had a shroud that closed in the opposite direction of that previously tested. The results were found to be consistent with the previous testing and demonstrated as long as the probes orientations are consistent between the burners (i.e. distance from register front plate and degree of rotation relative to register swirl direction) the IBAM indicated versus actual ASME flow measurement correlations were essentially unchanged.

In the field, AEP has two recently completed CCV low NOx burner retrofit installations incorporating two IBAMs per burner. One is on a 260 MWe sub critical opposed wall pulverized coal fired unit with 18 total burners unevenly split between the front and rear walls with 12 and 6 respectively. The other is a 1300 MWe supercritical opposed wall coal fired unit with a total of 96 burners evenly split between the front and rear walls in two high cell configurations. From both units, a random sampling of available data has been taken to get a relative indication of the IBAM value. Each set of data included control room readings, 18 and 36 point, respectively, economizer outlet flue sampling grid gas analyses and individual burner IBAM readings. The control room data included unit excess air probe readings of which there is a normal compliment of 6 and 12 respectively per unit. Of the three, the finer economizer outlet flue gas sampling grid analyses is naturally expected to be the most reliable representation of true excess oxygen levels.

Based upon the IBAM flow readings, primary air flows and pulverizer throughputs, the average excess oxygen profile was predicted and then compared in Figures 11 and 12 to the indicated excess oxygen profiles from both the gas sampling grid analyses and the unit excess air probes.

Note that this comparison has been made with the assumption that all burner conduits from a single pulverizer have balanced primary air and coal flows, burners flames within a column do not mix with flames from adjacent burner columns and all reactions within a burner column are complete. While it is recognized that some degree of mixing does occur between burner columns and that there is some mal distribution between coal conduits, for both units, the IBAMs reasonably predict the profile created by the gas grid analyses and, in most cases, as well, if not, better than the unit excess air probes.

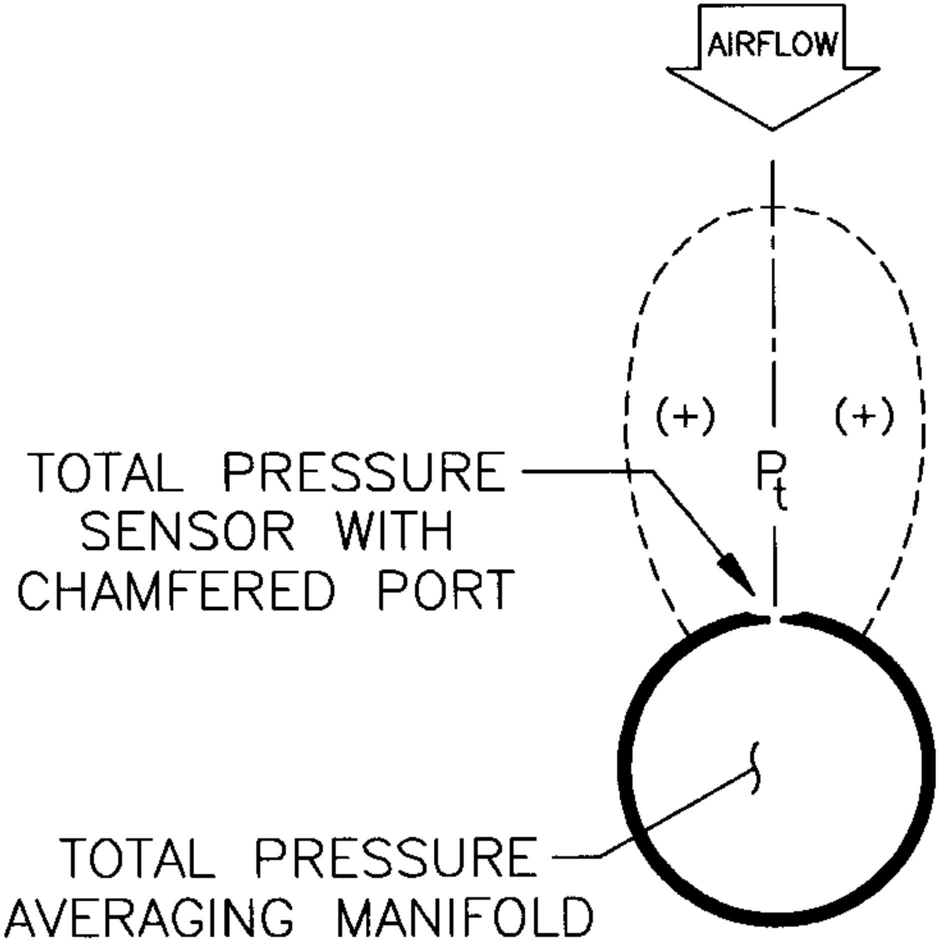

AIRFLOW
(+)
(+)
P_t
TOTAL PRESSURE SENSOR WITH CHAMFERED PORT
TOTAL PRESSURE AVERAGING MANIFOLD

Figure 1

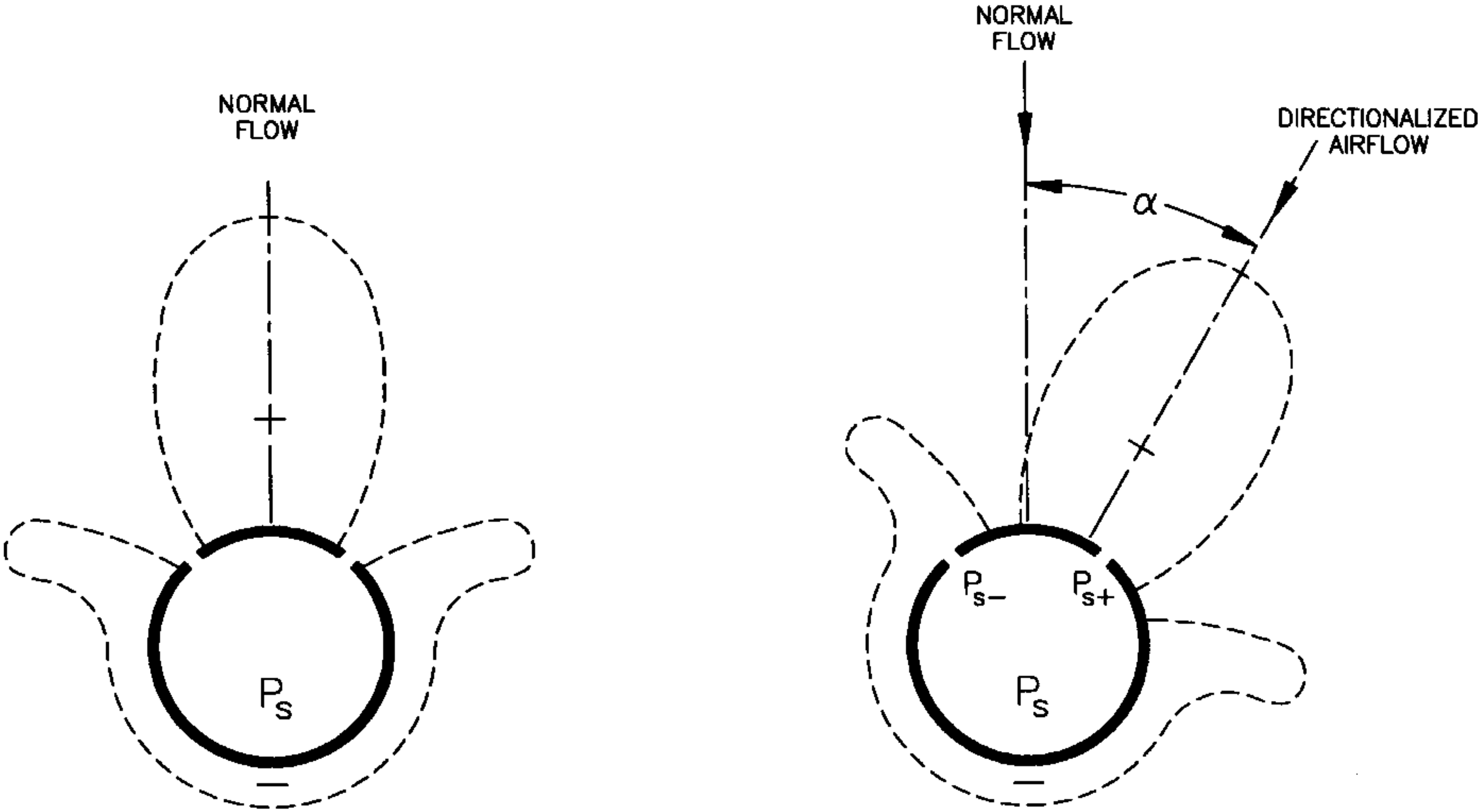
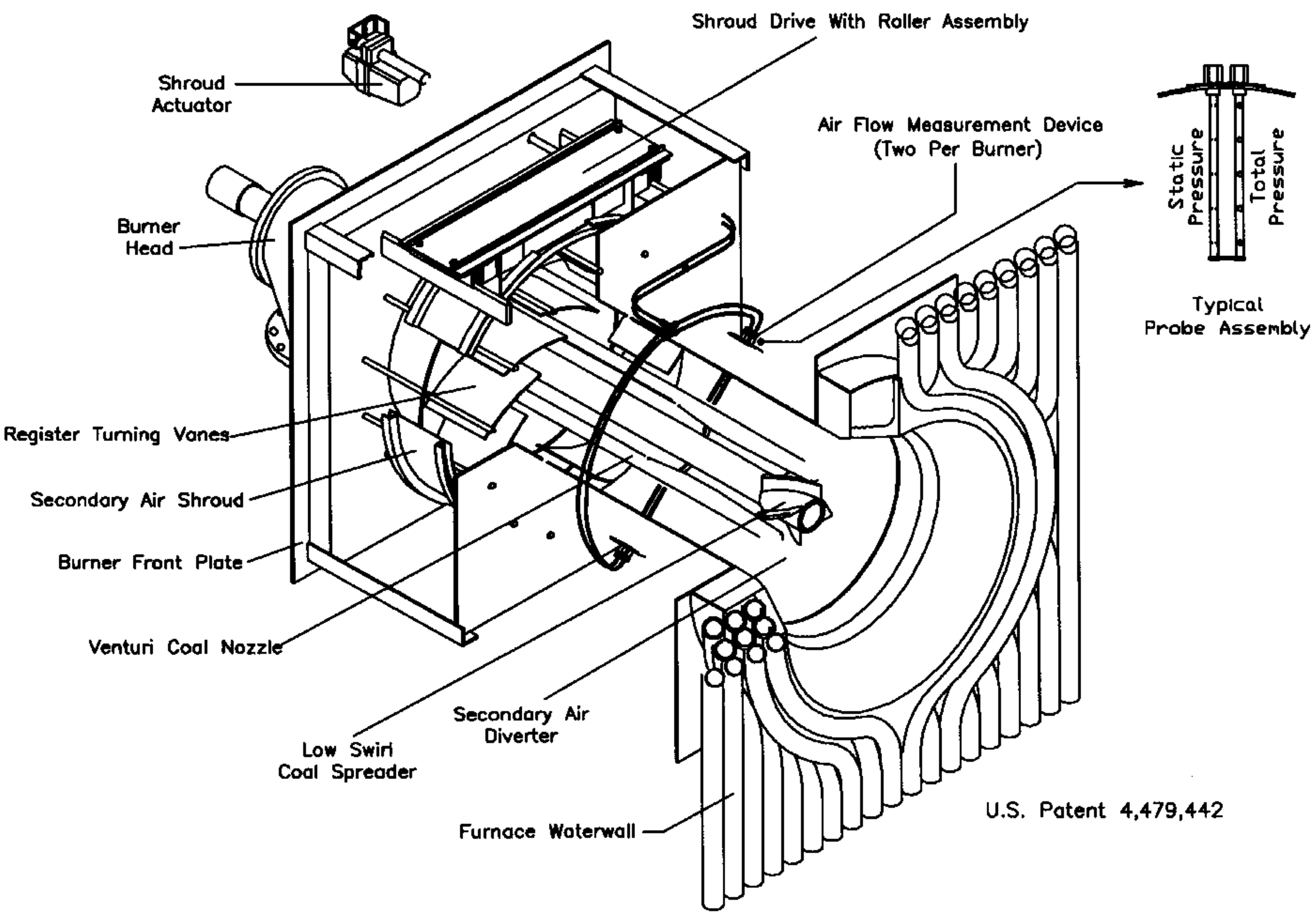

NORMAL FLOW
+
+
P_s
−
NORMAL FLOW
DIRECTIONALIZED AIRFLOW
α
+
P_{s-}
P_{s+}
P_s
−

Figure 2



Application of Air Monitor Air Flow Probes to
DB Riley Low NOx CCV Burner

Figure 3

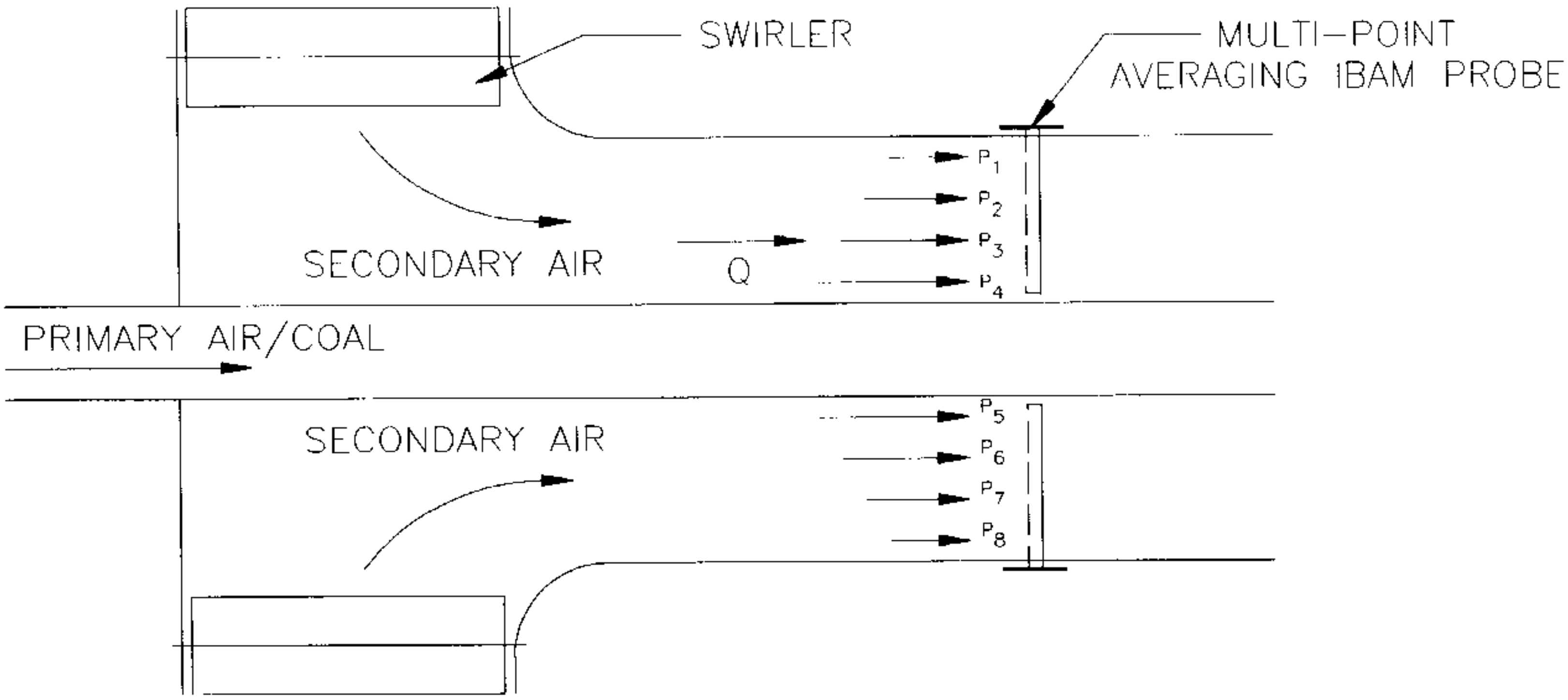

SWIRLER
MULTI-POINT AVERAGING IBAM PROBE
P_1
P_2
P_3
P_4
SECONDARY AIR
Q
PRIMARY AIR/COAL
P_5
P_6
P_7
P_8
SECONDARY AIR

Figure 4

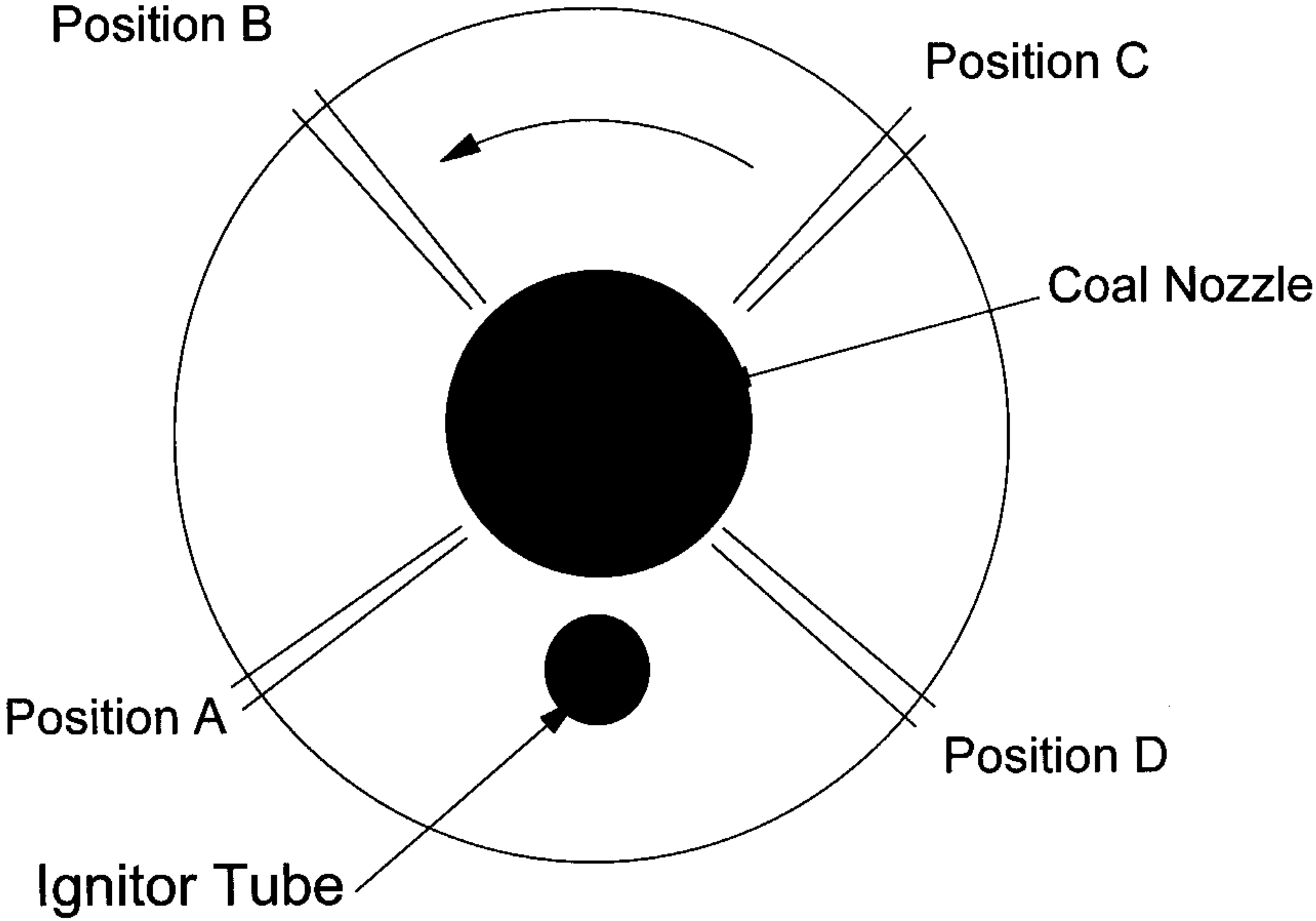

Position B
Position C
Coal Nozzle
Position A
Position D
Ignitor Tube

Figure 5

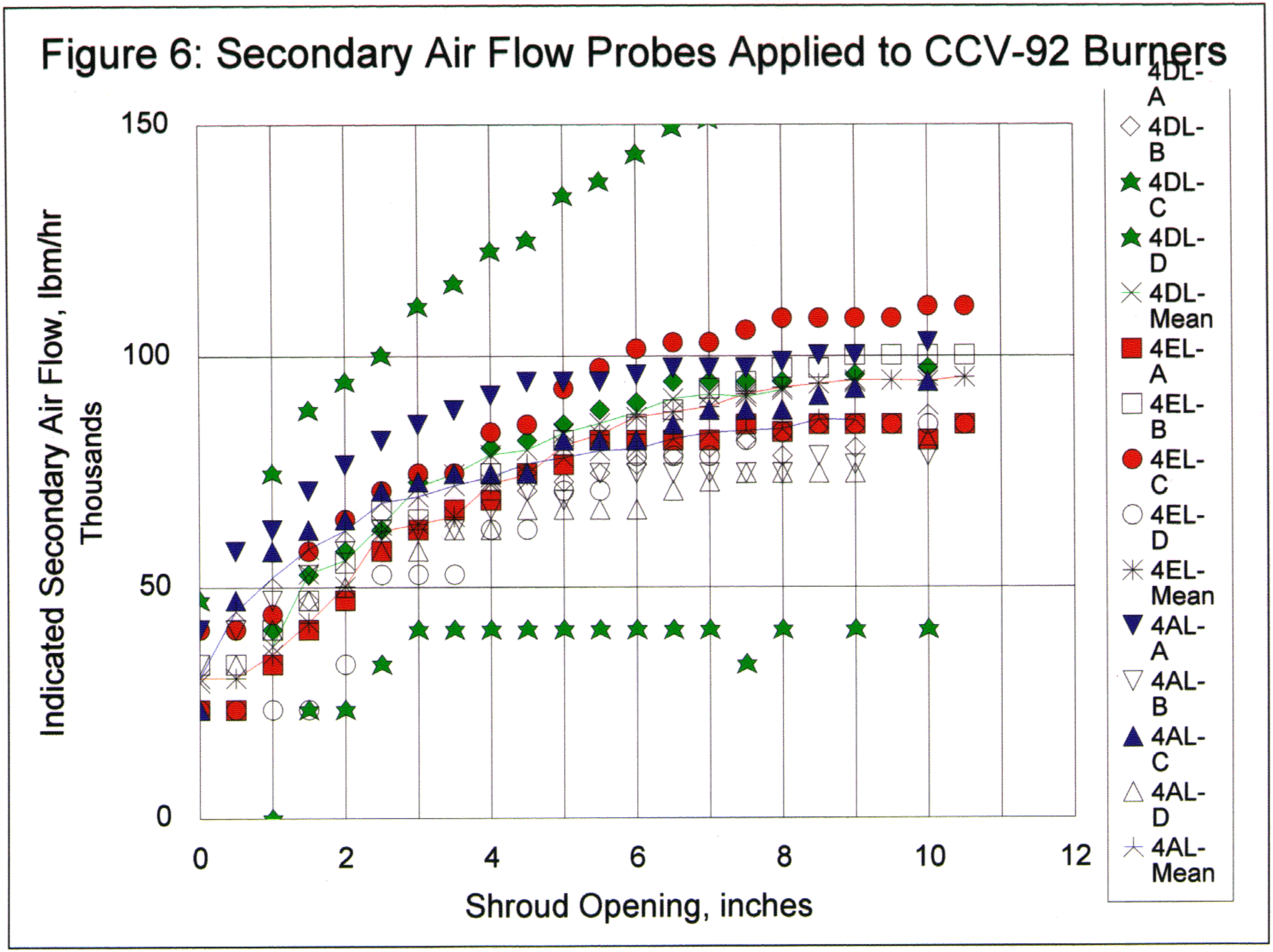


Figure 6: Secondary Air Flow Probes Applied to CCV-92 Burners

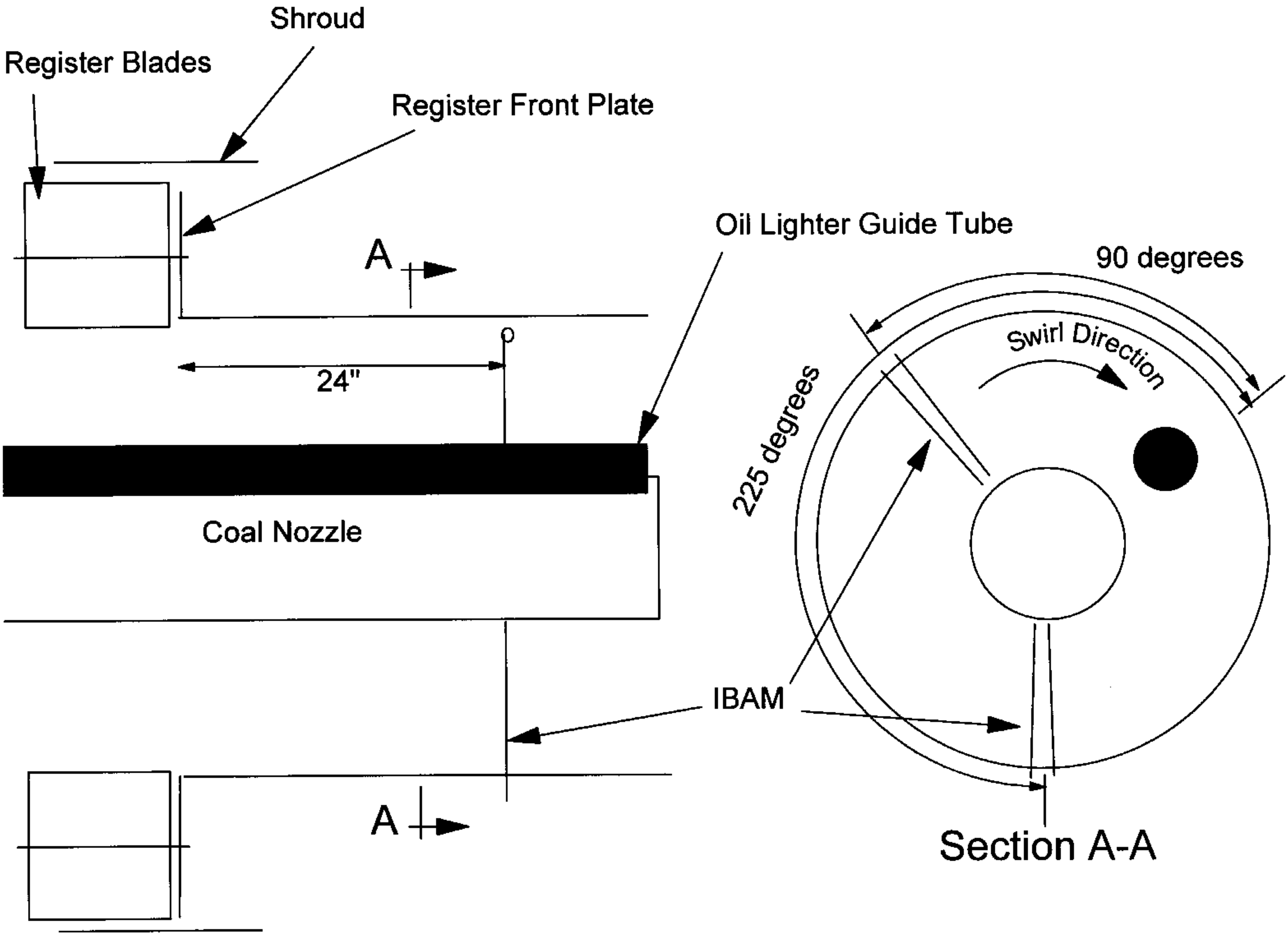


Figure 7: Base Case IBAM Orientations

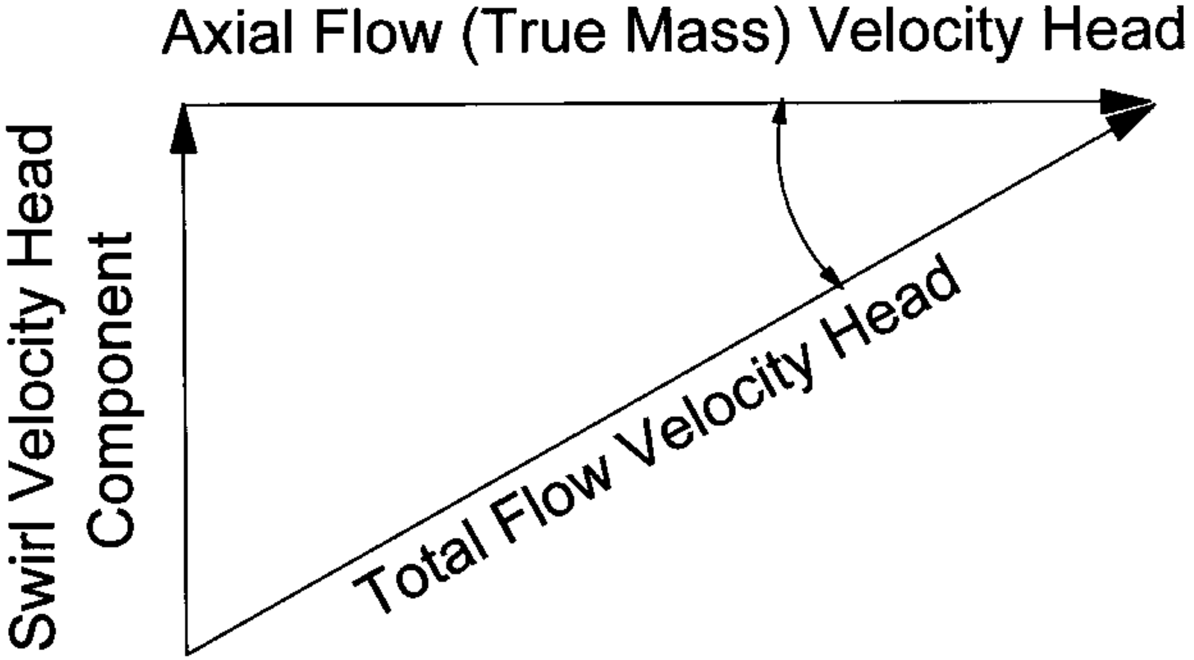


Figure 8: CCV Low NOx Burner Flow Field

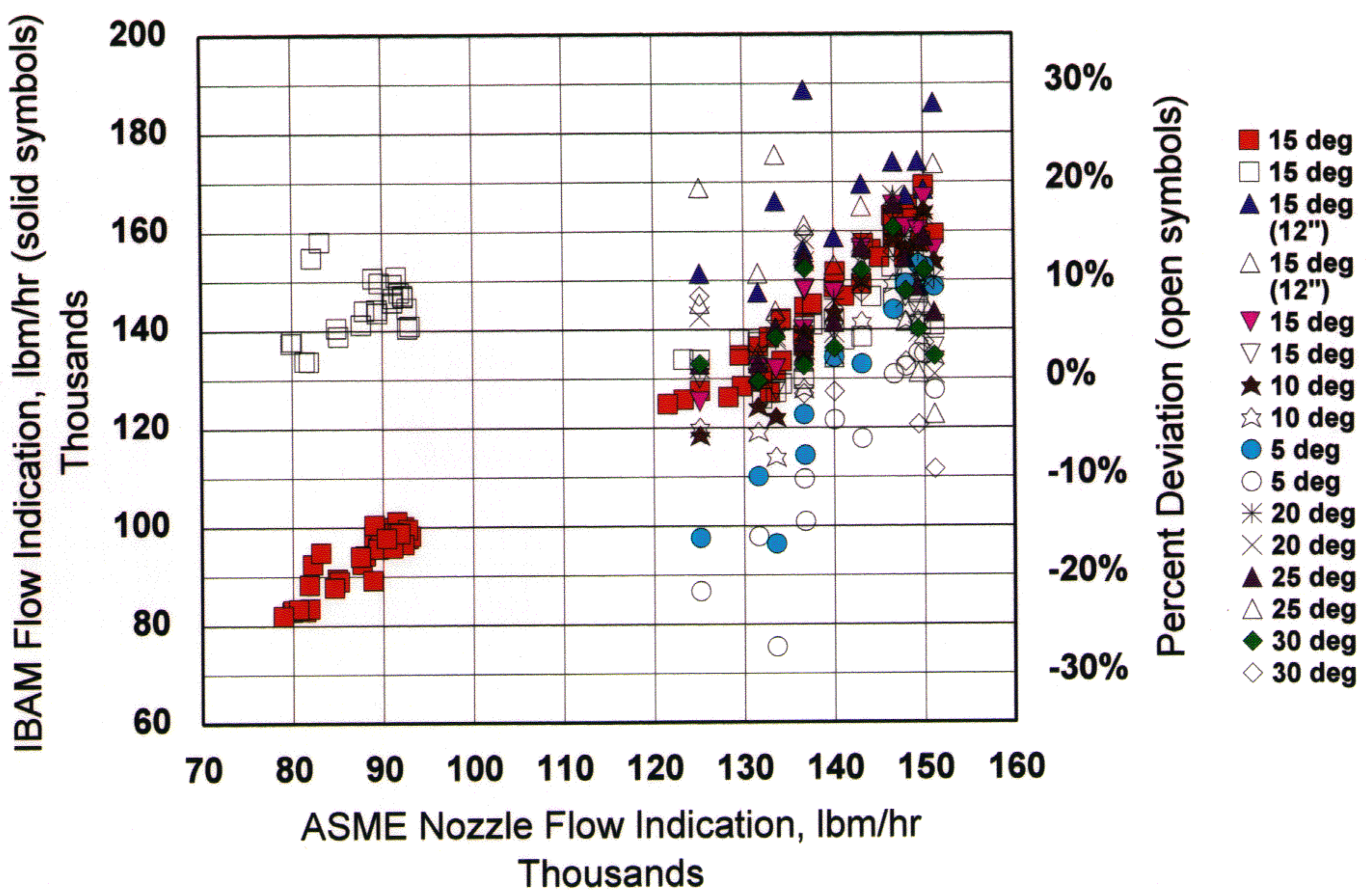


Figure 9: IBAM Flow Tests

All Tests with Cosine Flow Correction

Figure 10: ASME Nozzle vs. IBAM (15 degree) Correlation

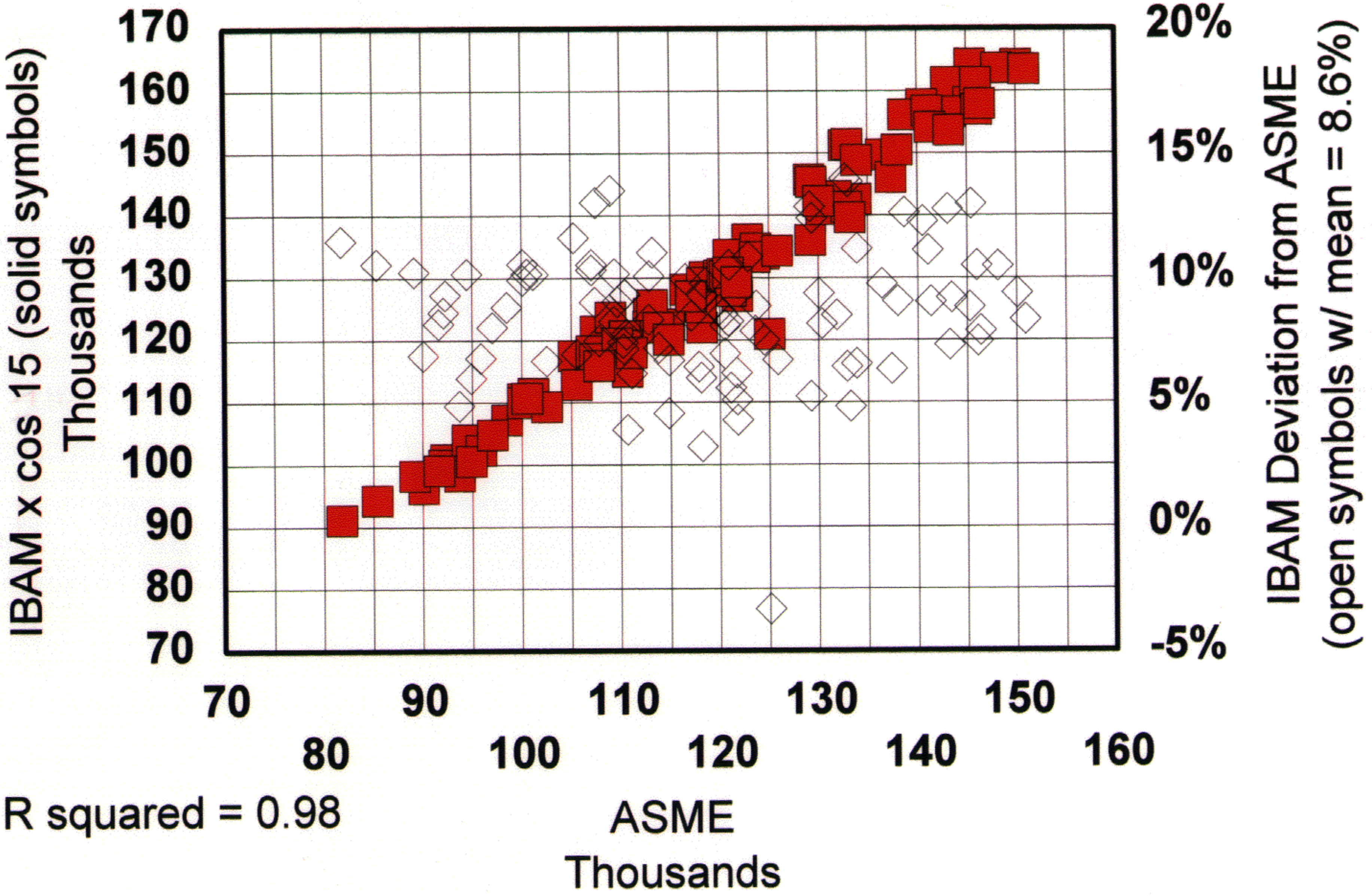
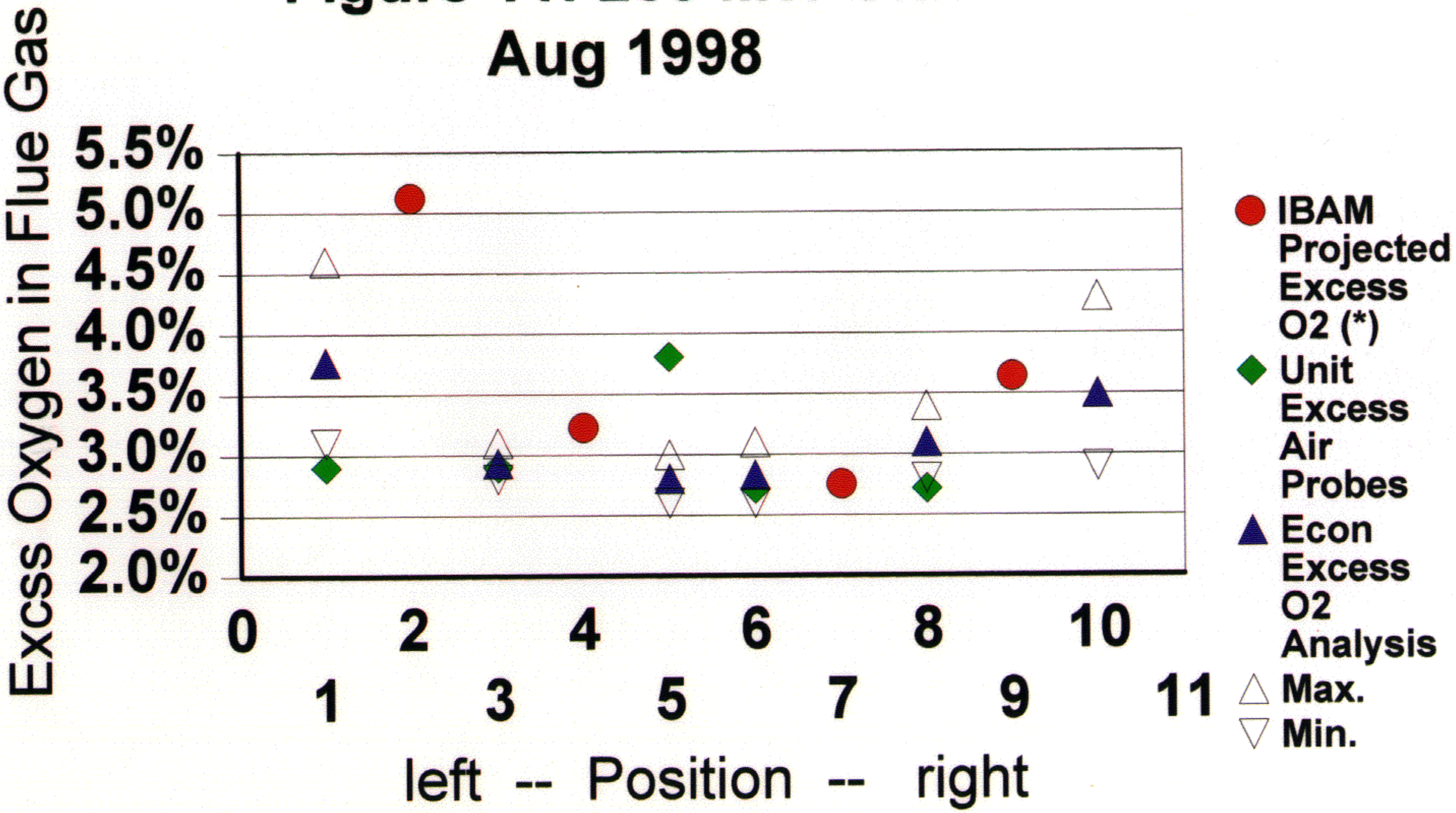


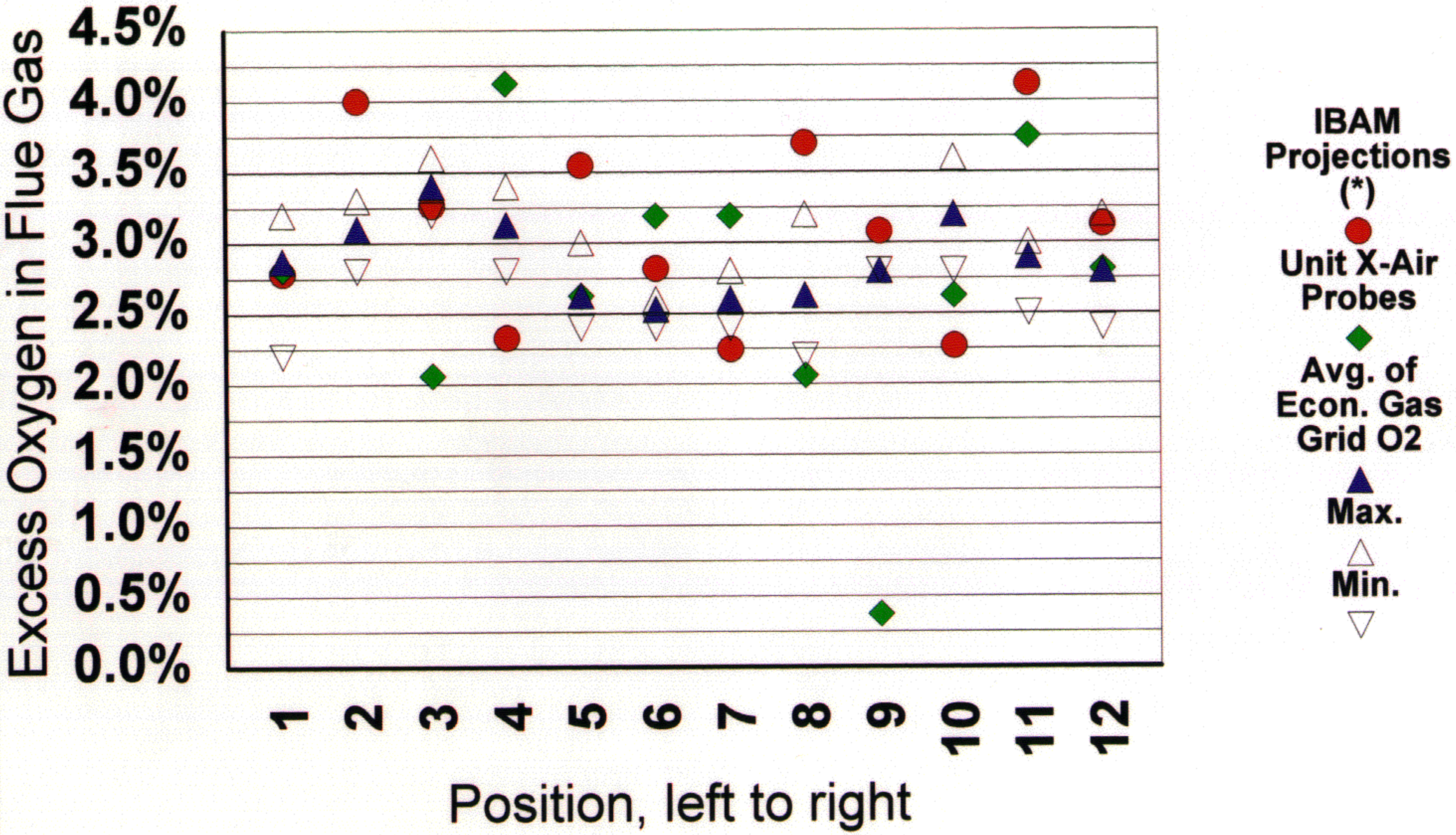
Figure 11: 260 MW Unit
Aug 1998



(*) - Assumes balanced coal flow between pipes, no interation between burner columns, and complete reactions within burner columns.

Figure 12: 1300 MW Unit

15-Jul-98



(*) - Assumes balanced coal flow between pipes, no interaction between burner columns, and complete reactions within burner columns.