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A NASA Spin-off Company

Your Fluid Flow Metering Specialists

APlus-QMC LLC
Paul van Buskirk
832-948-6872/832-515-5464

September 27, 2020 (May, 2002 Original)

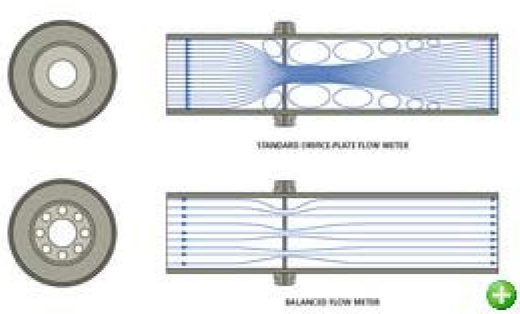
Subject: A+ Balanced Flow Meter Accuracy, Pressure Recovery, and 1-D Fitting Tests

® Patented World-Wide

Dear Client,

Balanced flow meters are recent additions to an established class of simple, rugged flow meters that contain no moving parts in contact with flow and are based on measurement of pressure drops across variable area flow paths. These flow meters are highly accurate, minimally intrusive, easily manufactured, and reliable. A balanced flow meter can be easily mounted in a flow path by bolting it between conventional pipe flanges. A balanced flow meter can be used to measure the flow of any of a variety of liquids or gases or 2 phases, provided that it has been properly designed.

As with any flow meter, calibration with your flange configuration is recommended. Field calibration is preferred, if required. Errors of *0.25% (total system)* or less are based on numerous NIST facility tests in both air and water environments, with multiple pipe sizes and plate designs and configurations. A design-of-experiments testing regime was completed, after preliminary screening (shown on Web); optimization testing was then used to find relations for number-of-holes, hole-angles, and hole-diameter to plate- thickness, etc. Based on a complex regression analysis and using dimensionless analysis, with many thousands of NIST-certified testing points, and with flows from Nre = 500 (or less) to maximum air/water velocities (Mach # >1), the global equation error was well within the 0.25% reported accuracy. Our software uses this design approach for your unique and each individual flow-plate application.



The fluid flow in the Balanced Flow Meter is straighter and less turbulent. One consequence is the net pressure loss downstream for the balanced flow meter is much less than that of the standard orifice-plate flow meter.

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The innovative aspects and advantages of a balanced flow meter are probably most easily understood by comparing it with its most closely related predecessor, a standard orifice-plate flow meter (see above figure). Any flow meter based on the aforementioned pressure-drop principle necessarily introduces some turbulence, permanent pressure loss, and concomitant dissipation of kinetic energy of flow. The turbulence, in turn, introduces a degree of non-repeatability into the measurements and increases the degree of uncertainty of the relation between differential pressure and the flow rate. Relative to the standard orifice-plate flow meter, the balanced flow meter introduces less turbulence and several times less permanent pressure loss and is therefore capable of offering a demonstrated *10 times greater accuracy and repeatability* with less dissipation of energy. Tests with our improved contoured-hole plate designs showed essentially no permanent pressure loss with *extreme accuracies below 0.15%* across a wide flow range. A secondary benefit of the reduction of turbulence is the reduction of vibration and up to *15 times less acoustic noise* generation. A *service life expectancy is increased by 15 times* due to reduced shear stresses, as demonstrated.

Both the balanced flow meter and the standard orifice-plate flow meter are basically disks that contain holes and are instrumented with pressure transducers on their upstream and downstream sides. The most obvious difference between them is that the standard orifice plate contains a single, central hole while the balanced flow meter contains multiple holes. The term “balanced” signifies that in designing the meter, the sizes and locations of the holes are determined in an optimization procedure that involves balancing of numerous factors, including volumetric flow, mass flow, dynamic pressure, kinetic energy, Reynolds number, all in an effort to minimize such undesired effects as turbulence, pressure loss, dissipation of kinetic energy, and non-repeatability and non-linearity of response over the anticipated range of flow conditions. Due to proper balancing of these factors, recent testing demonstrated that the balanced flow meter performance was similar to a Venturi tube in both accuracy and pressure recovery, but featured reduced cost and significantly reduced pipe-length requirements. With proper application of mal-distribution factors and fitting disturbance type, little affect is seen in accuracy or repeatability, but higher plate DP’s are required for effective flow conditioning dependent on flow Reynolds number. Fitting types included elbow, tees, and valves, with direct bolting of the balanced flow meter to upstream or downstream flange. *Distances below 1 pipe diameter may be and are used*. For these applications our engineers will require fitting type and pipe isometrics.

We are confident that you will be 100% pleased with the continued accuracy and repeatability of our A+ FlowTek Balanced Flow Meter plates. With performance that equals or exceeds that of the Venturi tube, as well as inherent flow conditioning, < 1-D fitting restrictions, reduced noise and vibrations, minimal or no permanent pressure loss, and built-in self-cleaning, venting and self draining features, the Balanced Flow Meter (BFM) flow-meter plate is specifically designed for your unique application to provide many years of trouble-free, dependable and money-savings service for each of your flow applications.

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As always, it is our pleasure in working with you on your flow projects. Thanks for all your assistance and recommendations! Please contact your A+ FlowTek representative for pricing, schedule, and any testing or certification requirements you may prefer.

If you require additional information please feel free to call me at 832-948-6872 at your convenience.

Thank you,

Paul van Buskirk
President
A+ QMC LLC.

Paul van Buskirk
Technical Director Co-Inventor
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A+ FLOWTEK
Balanced Flow Meter
Patent No. US 7,051,765 B1

SN60530001

8 inch, 0.5" thick, Beta 0.77318, Ring Joint Flange
Application: Well head gas and condensate flow
(high pressure 2-phase flow)

APB-3044 © 2008

Note: This invention is NASA and Worldwide Patented (U.S. Patent No. 7,051,765) and is the only patented multi-hole plate with circular holes.

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NASA/NIST Accuracy Testing Statement

For the supplied Balanced Venturi Meter (BVM) plates at your facility will meet 0.25% system accuracy and 0.15% plate accuracy and 0.05% repeatability requirements across the complete flow range; provided they have been installed per the APlus-QMC installation instructions provided in the data packs for these tags, the process parameters provided by Client that have been used in the sizing calculations are applicable, and discharge coefficients provided with the A+ accuracy report are used.

System errors of 0.25% or less are based on numerous NIST facility tests in both air, cryogenic, fouling, and water environments, with multiple pipe sizes and plate designs and configurations. A design-of-experiments testing regime was performed, and after preliminary screening (shown on Web); optimization testing was then used to find relations for number-of-holes, hole-angles, and hole-diameter to plate- thickness. Based on a regression analysis and using dimensionless analysis with thousands of testing points, with flows from Nre = 500 (or less) to maximum air (including sonic flows)/water (>30 ft/sec) velocities, the global equation error was well within a 0.25% reported system accuracy and 0.15% plate accuracy and repeatability accuracy. For gasses the super-compressibility factor for the Venturi Meter is used. Our software uses this design approach for each individual flow-plate application, and is completely successful in thousands of applications.

Typical calibration and error curves are shown below as typical 3 Sigma (99+ %) error for the NIST testing at NASA. This curve is for all flow loop equipment and is the total system error. Maximum total system errors are +/- 0.25%. The plate accuracy is within +/- 0.15% on this curve for Reynolds numbers above ~70,000. Below 70,000 the average kinetic energy correction factor, as given in the rigorous Bernoulli relation, affects the plate accuracy as this factor goes form a value of 1 (for turbulent flow) to a value of 2 for laminar flow at Reynolds<2100. This is a physical issue and affects all head meters, such as a Venturi, single holed orifice, etc. The KE correction factor is corrected in the discharge coefficient (Cd) value for these low Reynolds numbers.

The kinetic energy (KE) correction factor is dependent on Reynolds number (Re) and may be determined from symmetry for a multi-holed plate. A KE corrected plot and uncorrected plot for KE, e.g. average velocity KE, affects is provided in an accuracy report. A plot will show the total system error to be below 0.25% when following A+, NASA, and industry guidelines. The Balanced Venturi Plate error is 0.15% for low Reynolds number flow ranges. Note: Flows to maximum and sonic velocities show no deviations above the 0.25%. The correction factors are derived from basic physic relationships in the rigorous Bernoulli Equation.

The NASA testing included assignment and verification of all components in the flow loop; e.g. dP transmitter accuracy, tap location, plate orientation, pipe ID, pipe roughness, fouling affects, upstream and downstream fitting location affects, accuracy of temperature and pressure transmitters (for density). The method of Miller for Sensitivity Coefficients was assigned to each component in the loop. All factors are reflected in total system accuracy of 0.25% total. Plate error and repeatability from component analysis is 0.15. The installation instructions issued with each A+ plate must be followed to achieve associated accuracies in the field.

All testing was performed at NASA/Marshall Space Flight Center (MSFC), a NIST Certified Master Facility. MSFC also provided all personnel, instrumentation and data logging equipment. Calibration of all instrumentation, sensors, and turbine meter were performed at MSFC. Facility testing was performed to meet all required NIST, ISO, ASME, API, and GPSA standards.

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Cd & Beta Affects:

Comparison of Balanced Flow Meter with Orifice and Venturi Flow Meters

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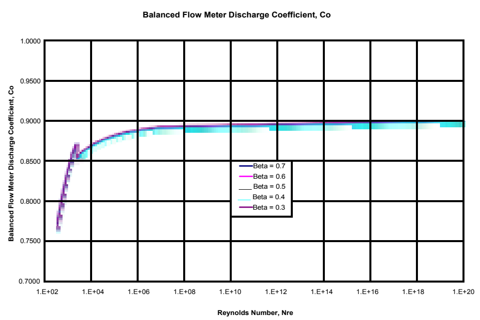
Balanced Flow Meter
Patented 10 / 750,628

Balanced Venturi Flow Meter Discharge Coef (Cd)



PPR-501-3
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Balanced Flow Meter Cd vs. Nre, at Various Betas

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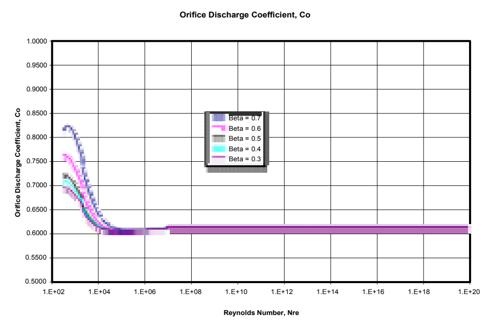
Orifice Discharge Coef. TYP



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Orifice Cd vs. Nre, at Various Betas

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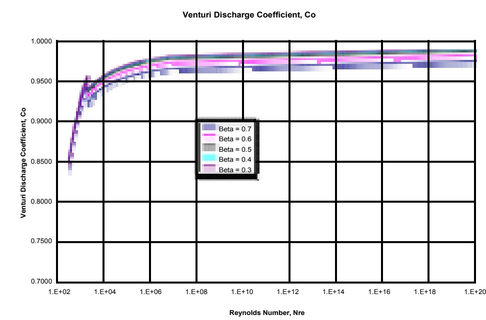
Venturi Discharge Coefficient, TYP



Venturi Cd vs. Nre, at Various Betas

Note: Minimal-No Beta Affect with Balanced Venturi Plate

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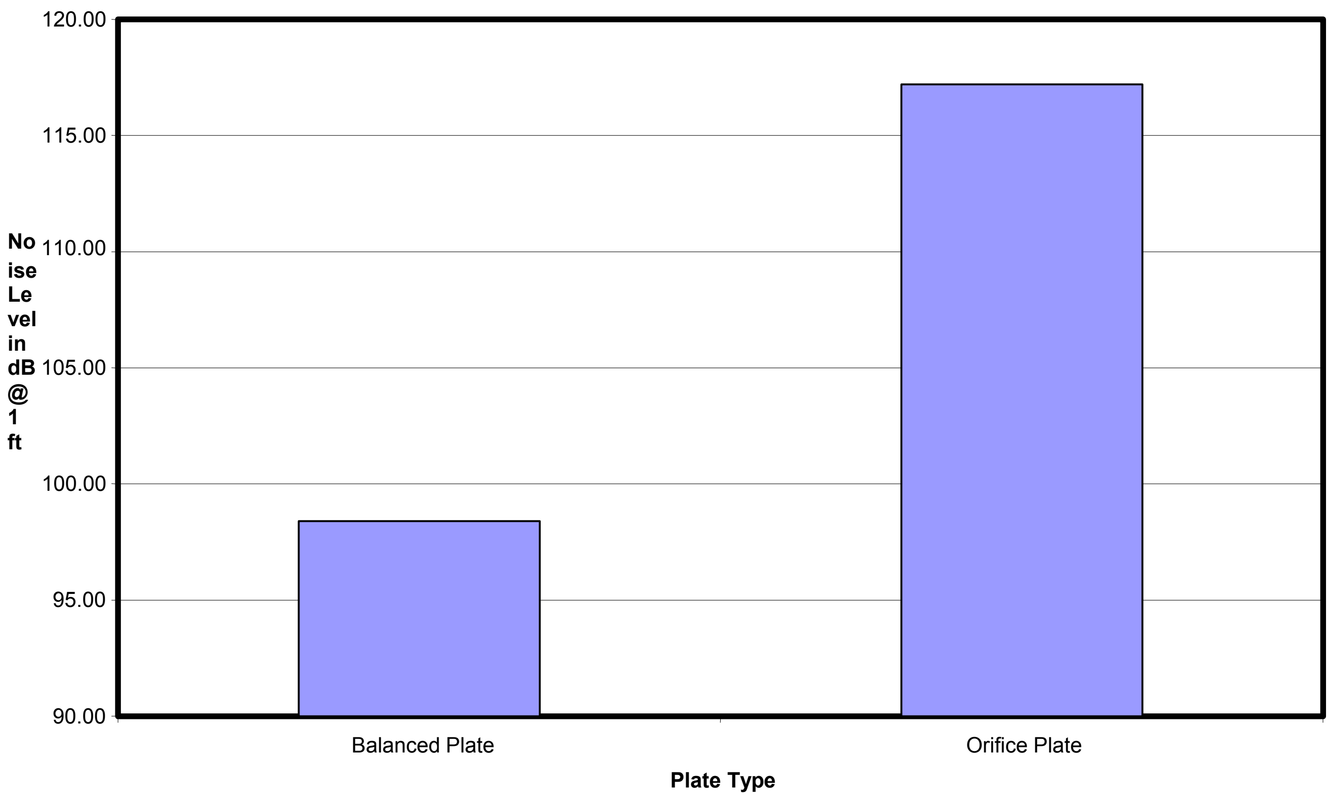
Flow Meter Noise @ 1 ft and 100% Air Flow



Note: Acoustics at 1 ft due to minimize background noise affects. (Note: BVM below 85 dB).

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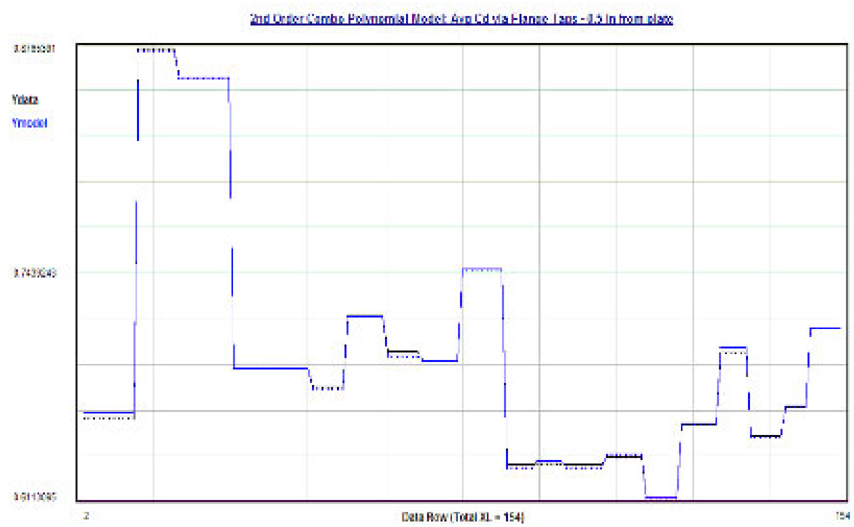
BFM Hole Layout Testing Square Cut Plate

Flow H2O Meter Test Cd Curve Fit Accuracy

Rel. Err.% 0.160, Std Dev% 0.158, Err. Range ~ 0.475 (+/-)%



Note: Effect of fittings causes increased conditioning pressure loss due to flow-field/velocity re-distribution. Affects calculated as A+ Program option for fitting L/D < 5. Mal-distribution requires additional DP across plate as a function of Reynolds number. Typically for light gasses DP must be greater than 2 in-H2O, for liquids > 20 inch-H2O. Low Reynolds numbers may require ~ double these amounts for flow range.

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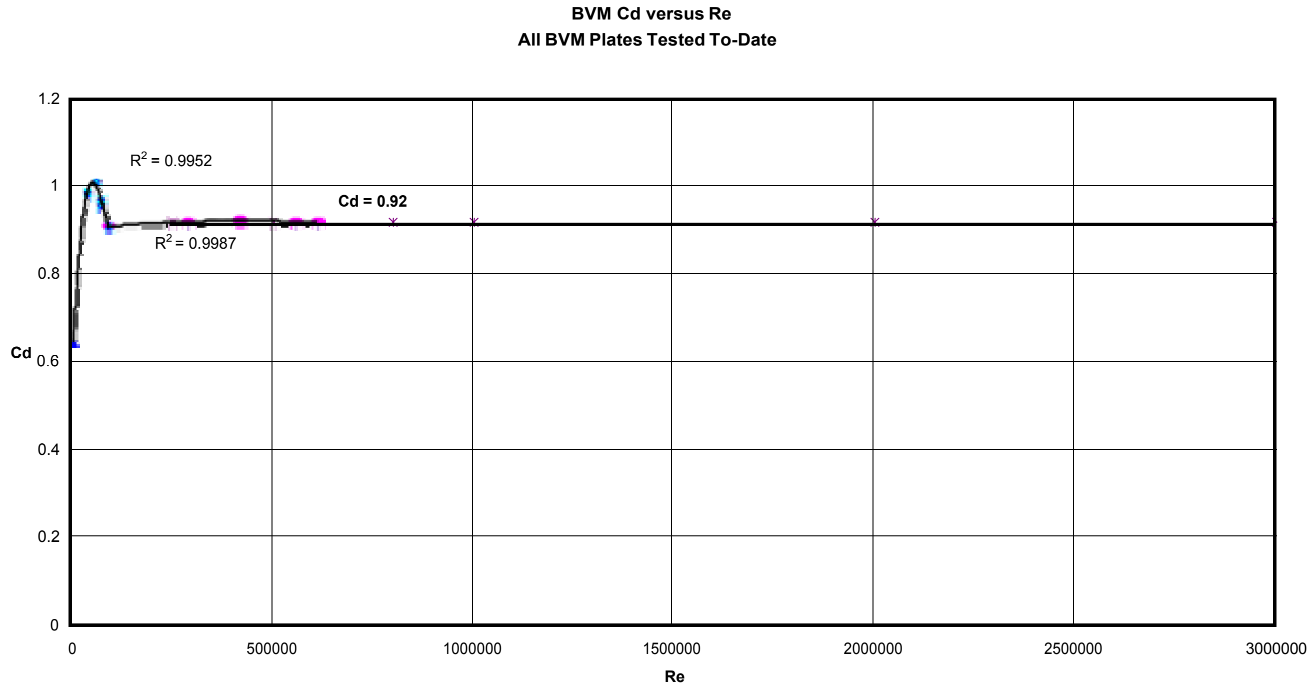
BVM H2O Design Cd Accuracy Testing

(Matches or Exceeds Venturi Flow Meter Performance)



Note: High Reynolds numbers are extrapolated to sonic flow for plates in air tests. Water testing includes various plate sizes and betas from 0.5 to 0.8, with contoured holes. Accuracy within 0.25% at flows above 50,000 w/o Reynolds Cd corrections. Cd values adjusted with dimensionless factors. "Low Reynolds- Hump" due to change in kinetic energy correction factor, e.g. physics in factor going from 2 in laminar flow to 1 at high turbulent Reynolds numbers which is known, calculable and can be field corrected.

Affect of fittings causes increased conditioning pressure loss due to flow-field/velocity re-distribution. Affects calculated as A+ Program option for fitting L/D < 5. Mal-distribution requires additional DP across plate as a function of Reynolds number. Typically for light gasses DP must be greater than 2 in-H2O, for liquids > 20 inch-H2O. With fitting affects, low Reynolds numbers may require double these amounts.

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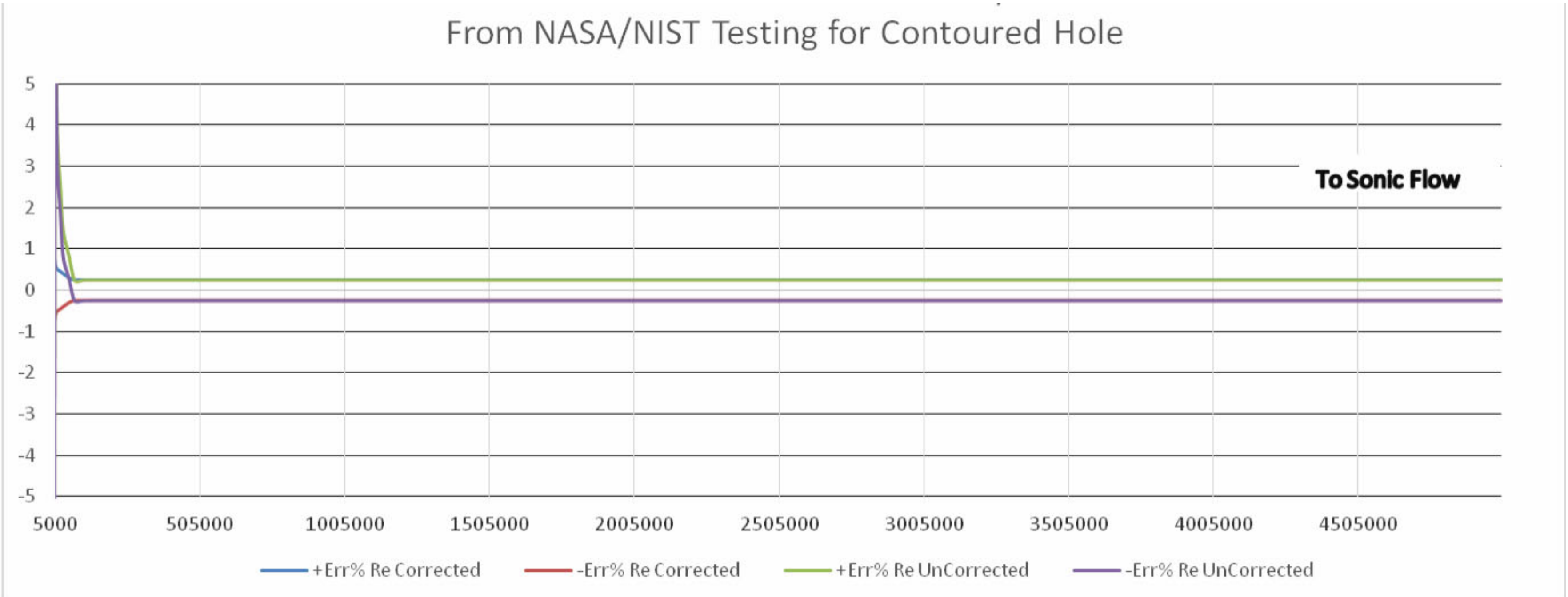
BVM (Contoured Hole) Error Curves (Low Nre errors are field corrected by KE factor analysis):



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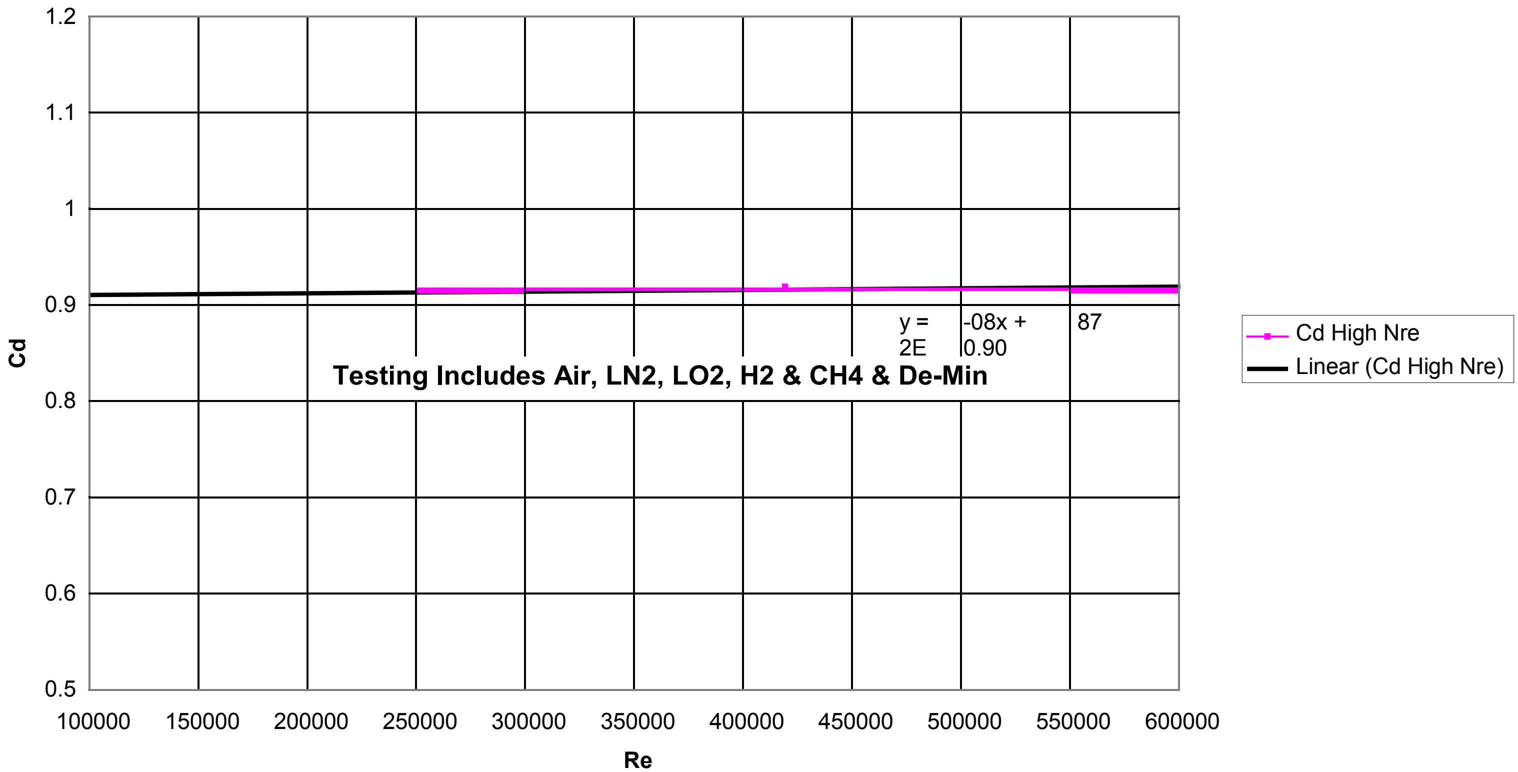
Cd versus Re

11/2, 2, 4, & 8 inch with 0.5, 0.6, 0.65, 0.72, & 0.8 Betas BVM Plates Tested

Cd Values Linearized by Dimensional Analysis for 2nd Order Affects

Data Based On Over 10,000 Data Points as Tested In NASA NIST Certified Facility



Note: Certain tests included fittings up and down stream, Cd adjusted by dimensionless factors for fitting affects.

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SN73330001

6 inch, 0.50” thick, Beta 0.72, BVM Application: HP-Compressor surge control, safety critical

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SN73390001

12 inch, 0.50” thick, Beta 0.69713, BVM
Application: Thermal incinerator feed

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SN61880001

4 inch, 4.00" thick, Beta 0.77672

Application: Liquid effluent high viscosities recycle

Note: BVM Separate Option Taps integral with plate. Centered, offset tap drilled directly into hole for direct Venturi affect. Plate-spool located on fitting outlet. <u>No other flow measurement system</u> could meet specs and field requirements. BVM standard is flange taps.

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