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Pressure Drop and Acoustical Application Guidelines for HVAC Plenums

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ABSTRACT

New equations derived from the recent ASHRAE-sponsored research project RP-1026 will enable HVAC system designers to better predict aero-acoustic performance of sheet metal plenums. This paper deals primarily with the aerodynamic performance of flow-through plenums and presents new total pressure drop equations for some of the most common plenum configurations. Comparisons are made between these equations, computational fluid dynamics (CFD) analyses, and hand-calculation methods. The practical uses of plenums are discussed along with prescriptive rules of thumb to help designers implement plenums effectively into their systems for aerodynamic and acoustical benefits.

INTRODUCTION

Plenums have been used in HVAC designs since fans have been connected to ductwork. There are many different kinds of plenums encountered in typical HVAC designs, but they all consist of an enclosed volume under a positive or negative pressure and at least two openings to allow the passage of airflow. A plenum with a fan located inside is referred to as a fan plenum; all other kinds are flow-through plenums. Plenums are typically rectangular, constant cross-section boxes with multiple connections of smaller sizes. In commercial HVAC design, they are usually made using standard ductwork materials such as galvanized or stainless-steel sheet metal of an appropriate gauge or thickness as prescribed by SMACNA guidelines. Plenum walls are often covered with an acoustically absorptive material on their interior surfaces to reduce noise transmission down the duct path(s) and/or to provide thermal insulation.

Flow-through HVAC sheet metal plenums are found in various places in duct systems. Discharge and exhaust plenums are probably the most common type of HVAC plenums and are typically connected to one fan and multiple duct runs. Return air plenums are used in low-pressure duct systems as a means to collect multiple return air ducts into a common location before entering an air-handling unit. Mixing plenums are often attached to the inlet side of air-handling units to blend outside air and return air as an effective means to reduce the heating or cooling load on the coils and to help with humidity control. Plenums can also be placed behind louvers or grilles as a means to distribute the airflow over the entire opening. These plenums are often sized to allow access for maintenance personnel to inspect or clean out any foreign debris.

HVAC systems also make use of architectural plenums that are constructed using building materials other than sheet metal ductwork. Architectural plenums are often used in lieu of sheet metal plenums typically due to cost, space, or location constraints. A room can serve as a plenum for an air-handling unit with an unducted inlet that draws air into the room from other openings such as fresh air or outdoor air inlets and building return air inlets. A ceiling plenum is the volume of space defined by a suspended ceiling and the structure above and is often used in HVAC design as a means to provide paths for air to return to an air-handling unit. Architectural plenums can be used to provide low-velocity air distribution, as in concert halls, where generated noise from air movement must not be audible. Raised floor systems are used in many data centers as plenums to provide underfloor air distribution, which allows flexibility in equipment location coupled with an effective wire management system.

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Plenums found favor with acoustical engineers who realized their potential for providing low-frequency attenuation with the advent of Wells' work (1958). An acoustical plenum is a type of passive silencer that is most effective in the lower frequencies. HVAC system designers and acoustical engineers alike do not tend to use them in their designs for various reasons. It is the author's opinion that these reasons include a lack of understanding of or comfort level with their performance. Previous work on acoustical plenums has indicated a significant margin of error of ±10 decibels in anticipated acoustical performance. Recent work on acoustical plenums has reduced that margin of error substantially (Mouratidis 2003).

Plenums are commonplace and integral components in many designs. They are used for a variety of purposes but primarily as aerodynamic devices that distribute airflow through multiple duct paths within a limited space. Very little has been written about plenums in duct design texts, and the authors are not aware of any previous studies done on aerodynamic performance of HVAC plenums. They have been used primarily by mechanical systems engineers for use as flow-through plenums where they solve a particular aerodynamic problem and by air-handling unit manufacturers as fan plenums to contain un-housed centrifugal fans, or plenum fans, which have become quite popular in recent times. Even so, they remain misunderstood in their potential to help solve both aerodynamic and acoustical problems.

The recent ASHRAE-sponsored research project, RP-1026, addressed flow-through type plenums (without internal fans) and quantified their acoustical performance in transmission loss and their aerodynamic performance in total pressure drop (Mouratidis 2003). RP-1026 focused on sheet metal HVAC plenums that are relatively simple and easy to quantify, unlike architectural plenums that can be complex in shape and construction. Eight different plenums of various sizes were analyzed with different wall types and inlet/outlet configurations that correspond to typical installations. New equations, replacing those developed by Wells, were developed that more closely predict the acoustical performance of plenums with various configurations. (See the final project report [Mouratidis 2003] for more information.)

DERIVATION OF PRESSURE DROP THROUGH BASIC IN-LINE MODELS

RP-1026 measured the aerodynamic performance of many different plenums in various configurations. As a baseline set, "in-line" plenums were constructed with a single inlet opening and a single outlet opening, both the same size and located opposite from each other with their centers lined up. Three square duct sizes were used for openings in this part of the project, measuring 12 × 12, 24 × 24, and 36 × 36 in., applicable to various plenum sizes. Round and oval duct sizes were not used in the investigation.

All test data were collected in the Vibro-Acoustics® laboratory, which is an accredited aero-acoustic test facility under the National Voluntary Laboratory Accreditation Program (NVLAP). The facility's large physical size made it an ideal environment for this study on large sheet metal test specimens.

Using the ducted test layout in accordance with ASTM standard E477 (ASTM 1999), the total pressure drop (TPD) was determined for 46 unique in-line plenum and duct size configurations. The ASTM standard defines the TPD as the measured difference between the total pressure two-and-a-half equivalent duct diameters upstream and five equivalent duct diameters downstream of the plenum. Using regression analysis, the TPD for all inline configurations (TPD_i) was found to be

$$TPD_i = 0.424 * P_v^{\ 0.901}\ , \qquad (1)$$

where

P_v = velocity pressure in the upstream duct measured in inches of water (in. H_2O) as defined by $P_v = (V / 4005)^2$, where V = mean duct velocity in feet per minute (fpm).

As indicated by the curve in Figure 1, the above equation produced a very good correlation coefficient of 0.94. Statistical analysis across all applicable test plenums and Equation 1 at a normalized inlet duct flow of 2000 fpm (or P_v = 0.249 in. H_2O) produced a standard deviation of 0.030 in. H_2O. Therefore, Equation 1 provides an accurate means to predict in-line TPD, independent of the plenum's internal dimensions, wall type, and opening sizes.

COMPARISON OF MEASURED AND CALCULATED PRESSURE DROP THROUGH A BASIC IN-LINE MODEL

The experimental results for one particular plenum analyzed in RP-1026 were compared with four prediction methods: the new derived equation from RP-1026 (Equation 1), computational fluid dynamics (CFD) analysis, and two other hand-calculation methods based on ASHRAE (2001) duct fitting tables and a fan engineering book (BFC 1983). Figures 2 and 3 show the CFD model of a 6 ft W × 4 ft H × 5 ft L plenum (internal clear dimensions)

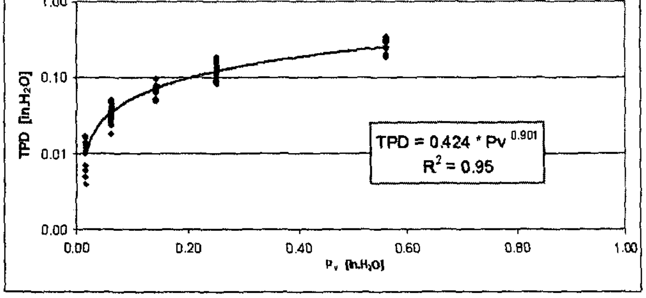

Figure 1 *In-line plenum pressure frop model, total pressure drop (TDP) vs. velocity pressure (P_v): n = 46 specimens.*

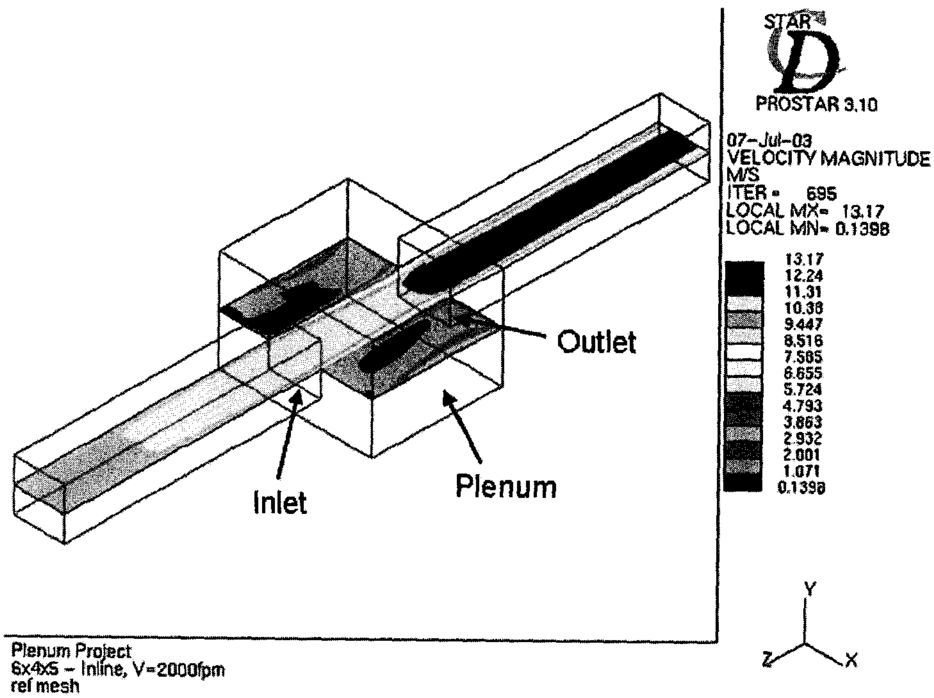

Figure 2 *In-line 6 × 4 × 5 ft plenum: mid-plane section, isometric view with velocity magnitude contours.*

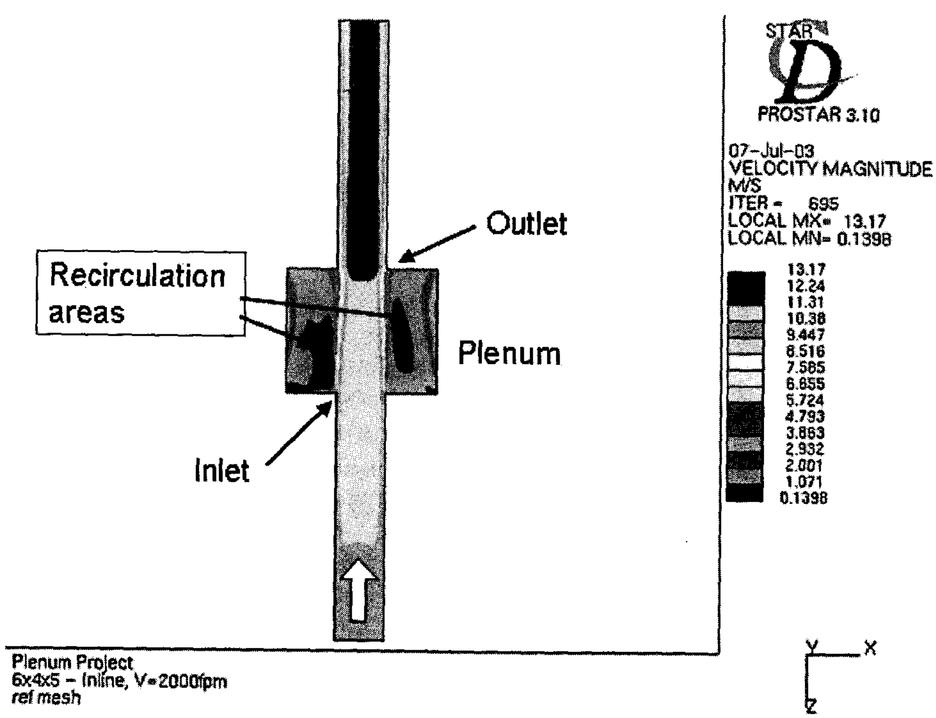

Figure 3 *In-line plenum: mid-plane section, plan view.*