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NT AND STATION TEST (VST) FACILITY DESIGN

stitute for Rapid Transit
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Interim Report

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Prepared by
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Division of
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VENT SHAFT and STATION TEST FACILITY

DESIGN REPORT

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THE DSI-AT 50' VENT SHAFT AND STATION TEST (VST) FACILITY

1. INTRODUCTION

In view of the fact that virtually no quantitative information is available regarding the airflow properties of subway vent shafts and stations, DSI-AT has undertaken the study of these properties and the design and construction of a unique test facility to obtain this missing, yet crucial data. The VST facility will supply the information required to characterize the airflow properties in subway vent shafts, transition sections, and stations in terms of rational parameters. These experimentally determined parameters will serve both as critical experimental inputs for the theoretical computer analysis and to provide needed guidance for effective experimental work in DSI-AT's subway aerodynamic test (SAT) facility.

2. ANALYTICAL CONSIDERATIONS

The detailed flow structure in the vicinity of a vent shaft or in a station is exceedingly complex. We must therefore turn to experiment for quantitative information. However, valuable insight can be gleaned from global analytical considerations. The theoretical analyses described in this section will serve to guide the experimental program by defining the relevant characteristic parameters and the functional form of their mutual interdependence.

2.1 VENT SHAFTS

The theoretical model for the flow in the vicinity of a vent shaft is depicted in Figure (1). Locally incompressible flow is assumed. From the figure it is seen that there must exist a dividing streamline between the exiting vent flow (region I) and the flow that remains in the tunnel (region II). Also from the figure, it is seen that the major losses are associated with the exiting mass flow. The remaining mass flow is essentially loss-free.

Now, the efflux of mass through the vent shaft will depend upon:

a) The static pressure level in the tunnel relative to atmospheric static pressure p_∞, (assuming that the vent shaft exhausts to p_∞). This we can characterize by $\Delta p = p_1 - p_\infty$.

b) The losses, ΔH_s, in the vent shaft duct itself assuming ideal ("straight-through") inlet conditions as depicted in Figure (2). These losses can be calculated directly from the data provided in many handbooks and textbooks (e.g. References (1) and (2)).

c) The losses, ΔH_i, associated with turning of the mainstream tunnel flow into the vent shaft, i.e., the difference between the losses which actually exist with the vent shaft "in situ" compared with those that would be produced if ideal "straight-through" inlet conditions into the vent shaft were provided.

The distinction between the two kinds of vent shaft losses will permit us to exploit the voluminous data on losses in corners, cascades, area changes, valves, grids, etc., already available in the literature.

The overall mechanical energy equation for the junction is written as follows:

$$(p_1 + \frac{1}{2}\rho V_1{}^2)\ \frac{\dot m_1}{\rho} - \Delta H_i\ \frac{\dot m_v}{\rho} - \Delta H_s\ \frac{\dot m_v}{\rho}$$

$$- (p_\infty + \frac{1}{2}\rho V_{v_e}{}^2)\ m_v/\rho - (p_2 + \frac{1}{2}\ \rho\, V_2{}^2)\ m_2/\rho = 0 \qquad \text{----(1)}$$

The mass equation is

$$\dot m_1 - \dot m_v = \dot m_2\ ,\quad \dot m_v = \dot m_{v_e} \qquad \text{----(2)}$$

Or, defining $C_{\dot m} = \dfrac{\dot m_v}{\dot m_1} = \dfrac{\rho A_v V_v}{\rho A\ V_1} = 1 - \dfrac{V_2\ A_2}{V_1\ A_1} \qquad (A_1 \neq A_2)$ ----(3)

equation (1), (2), and (3) are combined to give

$$\frac{p_1 - p_2}{\frac{1}{2}\rho V_1{}^2} + \frac{p_2 - p_\infty}{\frac{1}{2}\rho V_1{}^2}\ C_{\dot m} + 1 - C_{\Delta H_i} C_{\dot m} - C'_{\Delta H_s}\ C_{\dot m}{}^3 (\frac{A_1}{A_{v_e}})^2 \qquad \text{----(3A)}$$

$$- C_{\dot m}{}^3 (\frac{A_1}{A_{v_e}})^2 - (1 - C_{\dot m})^3\ (\frac{A_1}{A_2})^2 = 0$$

Where $C_{\Delta H_i} = \dfrac{\Delta H_i}{\frac{1}{2}\rho V_1{}^2}$

----(4)

and $C'_{\Delta H_s} = \dfrac{\Delta H_s}{\frac{1}{2}\rho V_{v_e}^2} = \dfrac{\Delta H_s}{\frac{1}{2}\rho V_1{}^2}\ (\dfrac{V_1}{V_{v_e}})^2$

where V_{v_e} is the average exit velocity

Rearranging eqn. 3A

$$C_{\dot{m}}\, C_{\Delta H_i} = \frac{p_1 - p_2}{\frac{1}{2}\rho V_1^{\,2}} + \frac{p_2 - p_\infty}{\frac{1}{2}\rho V_1^{\,2}} - C_{\dot{m}} + 1\,(1 + C_{\Delta H_s})\, C_{\dot{m}} \left(\frac{A_1}{A_{v_e}}\right)^2$$

$$- (1 - C_{\dot{m}})^3 \left(\frac{A_1}{A_2}\right)^2 \qquad \text{——— (5)}$$

Since from experimental measurements p_1, p_2, V_1, p_∞, $C_{\dot{m}}$, $C_{\Delta H_s}$, A_1, A_2 and A_{v_e} will be known, $C_{\Delta H_i}$ can be computed using equation 5.

Since there is a distinct difference between the physical mechanisms governing outflow and inflow for vent shafts it is important to consider them separately as is done in the following in order to better understand the experimental results and their simplest application to practical consideration.

Outflow

Figure 1 (a) shows the analytical model used in developing the equations of motion. The dividing streamline is considered to have no net momentum transfer across it and, the mechanical energy equations for regions I and II are respectively,

$$p_1 + \frac{1}{2}\rho V_1^{\,2} - \Delta H = p_\infty + \frac{1}{2}\rho V_{v_e}^{\,2} \qquad (1)$$

and $$p_1 + \frac{1}{2}\rho V_1^{\,2} = p_2 + \frac{1}{2}\rho V_2^{\,2}$$

where $\Delta H = \Delta H_s + \Delta H_i$

$\Delta H_s =$ straight through head loss in vent shaft

$\Delta H_i =$ inlet head loss.

The conditions downstream of the vent shaft will determine the impedence of the entire system after the vent shaft, and will therefore fix p_2, which is assumed to be known. Hence, defining

$$C_{\Delta p_2} = \frac{p_2 - p_\infty}{\frac{1}{2}\rho V_2^2}$$

and

$$C_{\dot{m}} = \frac{V_{v_e} A_{v_e}}{V_1 A_1}$$

$$C'_{\Delta H} = \frac{\Delta H}{\frac{1}{2}\rho V_{v_e}^2}$$

and noting that from continuity, assuming $A_1 = A_2$

$$\frac{V_1}{V_2} = \frac{1}{1 - C_{\dot{m}}} \qquad (3)$$

equations (1) and (2) may be combined to give

$$\frac{C_{\dot{m}}}{1 - C_{\dot{m}}} \frac{A}{A_{v_e}} = \sqrt{\frac{1 + C_{\Delta p_2}}{1 + C'_{\Delta H}}} \qquad (4)$$

Now, defining $C'_{\Delta H} = C'_{\Delta H_i} + C'_{\Delta H_s}$ which are normalized to the unit velocity of the vent shaft

we may expand as

$$C'_{\Delta H} = \left(\frac{C_{\Delta H_i}}{C_{\Delta H_s}} + 1 \right) C'_{\Delta H_s}$$

$$= (K + 1) \; C'_{\Delta H_s}$$

where $\qquad K = \dfrac{C'_{\Delta H_i}}{C'_{\Delta H_s}}$

The denominator on the right hand side of equation (4) can now be written as

$$\sqrt{1 + C'_{\Delta H}} = \sqrt{1 + (K + 1) \; C'_{\Delta H_s}} \qquad (5)$$

Substitution into equation 4 yields

$$\frac{C_{\dot m}}{1 - C_{\dot m}} \; \frac{A_1}{A_e} = \sqrt{\frac{1 + C_{\Delta p_2}}{1 + (K+1) \; C'_{\Delta H_s}}} \qquad (5a)$$

However if typical numerical values are substituted into equation (5) the following approximation is found to be a good one

$$\sqrt{1 + (K + 1) \; C'_{\Delta H_s}} \qquad \sqrt{(1 + C'_{\Delta H_s}) \; (1 + K)} \qquad (6)$$

for $K << 1$, $C_{\Delta H_s} >> 1$ (e.g. even if $K = 1$ and $C'_{\Delta H_s} = 3$ the following error using eqn. 6 is less than 7%)

Hence, equation (4) may be written using equation (6) as

$$\frac{C_{\dot{m}}}{1 - C_{\dot{m}}} \frac{A_1}{A_{v_e}} = \frac{1}{\sqrt{1 + K}} \sqrt{\frac{1 + C_{\Delta p_2}}{1 + C_{\Delta H_s}}} \qquad (7)$$

For purposes of data presentation, equation (7) is re-written

$$\frac{C_{\dot{m}}}{1 - C_{\dot{m}}} \frac{A}{A_{v_e}} \sqrt{\frac{1 + C'_{\Delta H_s}}{1 + C_{\Delta p_2}}} = \frac{1}{\sqrt{1 + K}} \qquad (8)$$

By plotting the data from the VST facility as indicated by equation (8) and in Figure (3), for the "in-situ" vent shaft, the influence of inlet head ;pss and overall vent shaft performance is defined in a universal and revealing format. It is not unlikely that the VST experiments will reveal that for most practical vent shafts, the parameter $1/\sqrt{1 + K}$ will assume some average value close to unity which may be considered universal for a particular type of inlet for purposes of engineering computation.

From equation (2), the static pressure rise coefficient across the vent shaft may be written as followe (normalized on V_1 and V_2 respectively).

$$C_{\Delta p_x} = \frac{p_1 - p_2}{\frac{1}{2} \rho V_1{}^2} = C_{\dot{m}}(C_{\dot{m}} - 2) \qquad (9)$$

or

$$C''_{\Delta p_x} = \frac{p_1 - p_2}{\frac{1}{2} \rho V_2{}^2} = \frac{C_{\dot{m}} (C_{\dot{m}} - 2)}{(1 - C_{\dot{m}})^2} \qquad (10)$$

Inflow

Figure 1(b) depicts the flow structure for vent-shaft inflow. It is seen that the dividing streamline now separates two flows of different head so that vorticity is generated along it. This line vorticity eventually becomes uniformly distributed over the entire cross-section of the tunnel by turbulent mixing. The resulting head loss due to this mixing is reflected in the following equations, where ΔH_{M_I} and $\Delta H_{M_{II}}$ represent the head losses in regions I and II respectively due to this mixing.

Defining

$$\overline{C}_{\dot{m}} = \frac{V_{v_e} \; A_{v_e}}{A \; V_2} \quad \text{(positive for inflow)}$$

and

$$\overline{C}_{\Delta p_1} = \frac{p_\infty - p_1}{\frac{1}{2}\rho V_1^{\,2}} \quad \text{(since upstream conditions now determine impedence)}$$

the mechanical energy equations may be written

$$p_\infty - \Delta H - \Delta H_{M_I} = p_2 + \frac{1}{2}\rho V_2^{\,2} \qquad (11)$$

$$p_1 + \frac{1}{2}\rho\, V_1^{\,2} - \Delta H_{M_{II}} = p_2 + \frac{1}{2}\rho\, V_2^{\,2} \qquad (12)$$

along with the continuity equation, assuming $A_1 = A_2$

$$\frac{V_1}{V_2} = 1 - \overline{C}_{\dot{m}}$$

These relationships may be combined to give

$$\overline{C}_{\Delta p_1} - 1 = \overline{C}_{\Delta H} \left(\frac{\overline{C}_{\dot{m}}}{1-\overline{C}_{\dot{m}}}\right)^2 \left(\frac{A_1}{A_{v_e}}\right)^2 + \frac{K_M}{(1-\overline{C}_{\dot{m}})^2} \qquad (13)$$

where,
$$K_M = \frac{\Delta H_{M_I} - \Delta H_{M_{II}}}{\frac{1}{2}\rho u_2^2}$$

Regarding K_M, we may make a number of observations:

1. $K_M = 0$ when $\overline{C}_{\dot{m}} = 0$

2. If the vorticity is distributed uniformly across the tunnel, $\Delta H_{M_I} = \Delta H_{M_{II}}$ and hence $K_M = 0$.

To within the rigor of straightforward engineering applications, this is a reasonable assumption to make.

Hence, equation (13) may be written

$$\frac{\overline{C}_{\dot{m}}}{1-\overline{C}_{\dot{m}}} \frac{A_1}{A_{v_e}} = \sqrt{\frac{\overline{C}_{\Delta p_1} - 1}{\overline{C}_{\Delta H}}}$$

$$= \sqrt{\frac{\overline{C}_{\Delta p_1} - 1}{\overline{C}_{\Delta H_s} + \overline{C}_{\Delta H_i}}}$$

$$= \sqrt{\frac{\overline{C}_{\Delta p_1} - 1}{\overline{C}_{\Delta H_s}(1+K)}} \qquad (14)$$

For data presentation purposes, we write

$$\frac{\overline{C}_{\dot{m}}}{1-\overline{C}_{\dot{m}}} \frac{A_1}{A_{v_e}} \sqrt{\frac{\overline{C}_{\Delta H_s}}{\overline{C}_{\Delta p_1} - 1}} = \frac{1}{\sqrt{1+K}} \qquad (15)$$

It is noted that this is very similar in form (but not identical) to the corresponding relationship for <u>outflow</u> (equation (8)) and is similarly plotted.

The pressure drop coefficient over the vent shaft now becomes (from equation (12)

$$\bar{C}_{\Delta p_x} = \frac{p_1 - p_2}{\frac{1}{2}\rho V_1^2} = \frac{\bar{C}_{\dot{m}}(\bar{C}_{\dot{m}} - 2)}{(1 - C_{\dot{m}})^2} + C_{\Delta H_{M_1}} \qquad -(14)$$

$$\bar{C}''_{\Delta p_x} = \frac{p_1 - 1_2}{\frac{1}{2}\rho V_2^2} = \bar{C}_{\dot{m}}(\bar{C}_{\dot{m}} - 2) + C_{\Delta H_{M_2}} \qquad -(15)$$

where

$$C_{\Delta H_M} = \frac{\Delta H_{M_{II}}}{\frac{1}{2}\rho V_1^2}$$

$$C_{\Delta H_M} = \frac{\Delta H_{M_{II}}}{\frac{1}{2}\rho V_2^2}$$

(Both forms are presented for convenience.)

The degree to which the mixing head loss coefficient $C_{\Delta H_1}$ or $C_{\Delta H_2}$ affect the static pressure rise will be investigated in and reflected by the VST experimental results.

In general, the unknown parameter $C_{\Delta H_i}$ will have the following dependence

$$C_{\Delta H_i} = f\,(Re,\ \Gamma,\ C_{\dot{m}},\ G_i^*)$$

where

$$Re = \frac{V_1 A}{\mu} \quad \text{(Reynolds number)}$$

$$\Gamma = \frac{\int_0^R \left(1 - \frac{V}{V_{max}}\right) dr}{\int_0^R \frac{V}{V_{max}} \left(1 - \frac{V}{V_{max}}\right) dr} \quad \text{(Pipe flow shape factor)}$$

$$G_i^* = \text{Inlet geometry of vent shaft}$$

Both Re and Γ can be eliminated on grounds that these orifice-type losses tend to be Reynold's number insensitive (within a factor of 100 or so to the actual condition) and that all cases of interest will be restricted to fully developed turbulent pipe flow upstream of the vent shaft, where $\Gamma \approx 1.4$ = constant (Reference 3).

2.2 TRANSITION SECTIONS

Tunnel transitions (e.g. circular to square, etc.) see Figure (4) occur frequently in subway systems and can constitute important sources of energy loss. While the experimental investigation of transition sections was not contemplated in the development of the original work statement, the existence of the VST facility makes it a relatively easy matter to quantitatively determine the pressure losses associated with this class of "junction".

Experimental data will be presented in terms of the total head loss coefficient

$$C_{\Delta H_t} = \frac{\Delta H_t}{\frac{1}{2}\rho V_1^{\,2}} \qquad \text{---- (10)}$$

where V_1 is the upstream velocity and ΔH_t is the total head loss produced by the transition. The static pressure change resulting is determined as follows:

$$p_1 + \frac{1}{2}\rho V_1^{\,2} = p_2 + \frac{1}{2}\rho V_2^{\,2} + \Delta H_t$$

where V_2 is the downstream velocity

$$p_1 - p_2 = \frac{1}{2}\rho\left(\frac{V_2}{V_1}\right)^2 V_1^{\,2} - V_1^{\,2} + C_{\Delta H_t}\ \frac{1}{2}\rho V_1^{\,2} .$$

Since, from Mass conservation

$$V_1 A_1 = V_2 A_2 ,$$

$$C_{\Delta p_x} = \frac{p_1 - p_2}{\frac{1}{2}\rho V_1^{\,2}} = \left(\frac{A_1}{A_2}\right)^2 - 1 + C_{\Delta H_t} \qquad \text{----(11)}$$

2.3 STATIONS

If the station cross-sectional area is large with respect to the incoming tunnel area, and if the station length is large compared to the tunnel diameter, i.e., if

$\frac{WH}{A} >> 1$, W = Station width
H = Station height

and $\frac{L_s}{D} >> 1$, L_s = Station length

Then the station can be assumed to behave like a plenum chamber. Since the above requirements are virtually always satisfied in actual subway stations, we shall proceed under this assumption.

Consider a station as shown in Figure (5) which has N exit orifices. The term orifice will be used to denote all openings to the atmosphere, whether they be vent shafts, stair wells, exit tunnels, etc.

Since the station is assumed to behave as a plenum, then we can generate N simultaneous equations for the orifices as follows:

$$p_o - p_\infty = (1 + C'_{\Delta H_{s_1}}) \frac{1}{2} \rho V^2_{ve_1}$$

$$p_o - p_\infty = (1 + C'_{\Delta H_{s_2}}) \frac{1}{2} \rho V^2_{ve_2}$$

$$p_o - p_\infty = (1 + C'_{\Delta H_{s_3}}) \frac{1}{2} \rho V^2_{ve_3}$$

The $C_{\Delta H_s}$ is approximately the loss for a perfect or ideal inlet condition (straight-through) since the inlet fluid is stagnant.

In shorthand notation,

$$p_o - p_\infty = (1 + C'_{\Delta H_{s_j}}) \frac{1}{2} \rho V^2_{ve_j} \quad j = 1, 2, 3, \qquad ----(12)$$

These equations must be solved simultaneously to give the magnitudes of the velocities through the various orifices. Knowing this, the total station mass flow coefficient $C_{\dot{m}}$ is obtained directly as

$$C_{\dot{m}} = \frac{\dot{m}}{\rho A V_1} = \frac{\sum V_{ve_j} A_{ve_j}}{V_1 A} \qquad ----(13)$$

However, the stagnation, or plenum pressure appearing in equation (12) is not equal to that of the flow entering from the tunnel since this flow suffers a loss in total head ΔH_a due to the sudden expansion at the inlet. Using the energy equation,

$$p_o = p_1 + \frac{1}{2}\rho V_1^2 - \Delta H_a$$

Defining $C_{\Delta H_a} = \dfrac{\Delta H_a}{\frac{1}{2}\rho V_1^2}$, $C_{\Delta p} = \dfrac{p_1 - p_\infty}{\frac{1}{2}\rho V_1^2}$ ----(14)

we obtain

$$p_o - p_\infty = (C_{\Delta p} + 1 - C_{\Delta H_a}) \frac{1}{2}\rho V_1^2 \qquad ----(15)$$

for the stagnation or plenum pressure.

Equation (15) supplies the required value of $p_o - p_\infty$ for use in equation (12) and subsequently, equation (13).

$C_{\Delta H_a}$ can be roughly estimated if no other information is available from handbook data on sudden expansion.

This simple model of station behavior will be verified in the VST facility. If this is found to be a reliable description of the actual situation, the above development may be used directly in the "VENT" program.

In cases where the station geometry is too complex to permit idealizing as above, the particular station under consideration will have to be replica-tested in the VST facility independently. However, the rational application of the above method should provide reliable results for a wide range of station geometries.

3. 50' VST FACILITY OPERATION & PROCEDURES

The general configuration of the VST facility is depicted schematically in Figure (6). It consists of a plenum box 4'x5'x6' supplied with air at 1.75 psig at a volume flow rate up to 4800 cfm*. Air flows from the plenum into a 12" i.d. tube (same tube used in moving vehicle test facility) in which the mass flow rate is measured by means of a DISA hot wire mass-flow meter ($\dot{m}_1$). A tube length of 10' is provided downstream of the inlet to permit a fully turbulent flow profile to be developed.

At the downstream end of the rig is the ETL (effective tube length) valve assembly which can be accurately adjusted by the mechanism indicated in the figure to simulate pressure drops corresponding to exit tube length/

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* Detailed design calculations and drawings of the VST Facility are found in the Appendices.

diameter ratios between 0 and ∞. The ETL valve assembly is mounted on a carriage so that it can be displaced axially to accommodate test sections varying between 0 and 50'. Just upstream of the ETL valve is another DISA mass-flow anemometer ($\dot{m}_2$).

Figure (7) shows the VST facility with a vent shaft assembly mounted as the test section, and Figure (8) shows a station similarly mounted. Stations up to 50' in length, corresponding to full scale lengths of 800 feet (based on a 16' tube diameter) can be accommodated.

3.1 VENT SHAFTS

Consider a vent shaft test section installed as indicated in Figure (7). A typical procedure might be as follows. Assume we wanted to perform a calibration on a particular type of vent shaft configuration, say one specified by the IRT which is typical or of particular interest. A replica model of this vent shaft would be built and calibrated first on the basis of ideal inlet conditions as shown in Figure (9) to determine $C'_{\Delta H_s}$, the straight-through pressure loss coefficient. The replica vent shaft would then be mounted to the model tunnel section as shown in Figure (7). For the fixed value of $C'_{\Delta H_s}$ in this case, the driving pressure coefficient $C_{\Delta p}$ is controlled by the ETL valve alone. By subtracting the readings $\dot{m} = \dot{m}_1 - \dot{m}_2$, the mass flow coefficient $C_{\dot{m}}$ is obtained. $C_{\dot{m}}$ is thereby obtained over an extreme range of $C_{\Delta p}$, resulting in the curve of Figure (3), for this particular inlet geometry and area ratio. Static pressure measurements made along the vent shaft test section will give the pressure change coefficient $C_{\Delta p_x}$ as defined in Figure (1). By throttling the exit of this vent shaft with different sized orifices, a family of curves can be generated as shown in Figure (3), to characterize the vent shaft over a range of $C'_{\Delta H_s}$*.

By selecting say three typical vent shaft geometries, and three typical area ratios, $A_v/_A$ (characterized by vent inlet area), the range of practical vent shaft parameters can be well bracketed. From the experimental data and further analysis, it is hoped that we may be able to derive a semi-empirical method for predicting $C_{\Delta H_i}$ directly. However, whereas a subway designer may have less control over the $C'_{\Delta H_s}$ of the vent shaft because of surface conditions, etc., there may be latitude for more idealized design of vent inlet to reduce $C_{\Delta H_i}$. If a reliable technique can be obtained for predicting $C_{\Delta H_i}$, the available VST data can be much more generally applied in the VENT program.

While it is a relatively simple matter to evaluate the performance of a wide variety of vent shafts in the VST facility, it is quite impossible to individually install all of these shafts in the Subway Aerodynamic Test

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* Procedure for determining $C'_{\Delta H_s}$ is shown in Appendix A.

(SAT) facility. Fortunately, this will not be necessary. In the SAT facility, simple flush-mounted circular vent shafts of a selected* $A_{V/A}$ will be fitted with variable orifice plates to achieve a range of $C'_{\Delta H_s}$ parameters. By varying $C'_{\Delta H_s}$ alone the performance of a large number of vent shafts corresponding to the curves generated in the VST facility on replica vent shafts can be reproduced. Given particular values for $C'_{\Delta H_s}$, $C_{\dot{m}}$, $C_{\Delta p_x}$ of the circular flush vent shaft installed in the moving vehicle facility, the VENT program can be checked against the actual run data in the moving vehicle facility (SAT).

To summarize, the most practical approach to the DSI-AT/PBQD interface with regard to vent shafts (and stations), appears to be as follows:

i) The VST facility will be used to generate performance curves for a range of replica vent shaft geometries. This data will be used directly in the VENT program.

ii) The SAT facility will be used to experimentally verify the accuracy of overall predictions of the VENT program.

3.2 STATIONS

The calibration of stations will proceed in a similar manner. However, first, the general flow patterns in typical station volumes will be investigated to determine the degree to which they diverge from the simple plenum model discussed in the preceeding section.

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* Representative of the most typical $A_{V/A}$ contemplated.

For this purpose, a variable geometry and variable venting station will be constructed so that $L_s/\sqrt{WH}$, WH/A, A_v/A and $C'_{\Delta H_{s_j}}$, $j = 1, 2, 3 \ldots\ldots$ and exit tube impedance can be varied. Tests similar in nature to those performed for the vent shafts will be conducted in order to determine to what degree of accuracy, the results of the simple analysis of the preceeding section are applicable.

The treatment of such complex things as mezzanines, stair-wells, etc., as if they were simple orifices will be investigated and methods for determining their $C'_{\Delta H_s}$ values will be determined on the basis of separate (component) tests. Once these component values have been determined, two replica stations of widely different geometry will be tested and the developed theory will be applied and compared with the experimental results. Any discrepancies will be tracked down and corrected.

The net result of this approach will be a series of empirical formulas for determining the equivalent $C'_{\Delta H_s}$ values of various components and experimental substantiations of the overall approach outlined in 2.3 for assessing station behavior.

Stations are too complex in general for the relatively simple parameterization obtained for vent shafts and transition sections, and hence the above approach is recommended.

4. NOMENCLATURE

A	Tunnel cross-sectional area
A_v	Vent shaft cross-sectional area (anywhere in shaft)
A_{v_e}	Vent shaft exit area
A_{v_i}	Vent shaft inlet area
$C_{\Delta H_i}$	Vent shaft inlet loss coefficient $= \dfrac{\Delta H_i}{\frac{1}{2}\rho V_1^{\,2}}$
$C_{\Delta H_s}$	Straight-through loss coefficient $= \dfrac{\Delta H_s}{\frac{1}{2}\rho V_{v_i}^{\,2}}$
$C'_{\Delta H_s}$	Straight-through loss coefficient $= \dfrac{\Delta H_s}{\frac{1}{2}\rho V_{v_e}^{\,2}}$
	i.e., $C'_{\Delta H_s} = C_{\Delta H_s} \left(\dfrac{V_{v_i}}{V_{v_e}}\right)^2 = C_{\Delta H_s} \left(\dfrac{A_{v_e}}{A_{v_i}}\right)^2$
$C_{\Delta p_x}$	Axial static pressure loss coefficient across vent shaft $C_{\Delta p_x} = \dfrac{p_1 - p_2}{\frac{1}{2}\rho V_1^{\,2}}$
$C_{\Delta H_t}$	Transition section loss coefficient $C_{\Delta H_t} = \dfrac{\Delta H_t}{\frac{1}{2}\rho V_1^{\,2}}$
$C_{\Delta H_a}$	Station flow entry loss coefficient $C_{\Delta H_a} = \dfrac{\Delta H_a}{\frac{1}{2}\rho V_1^{\,2}}$
$C_{\Delta p}$	Vent driving pressure coefficient $C_{\Delta p} = \dfrac{p_1 - p_\infty}{\frac{1}{2}\rho V_1^{\,2}}$

$C_{\Delta p_s}$	Straight-through static pressure change through vent shaft $C_{\Delta p_s} = \dfrac{p_o - p_\infty}{\frac{1}{2}\rho V_{v_i}^{\;2}}$
$C'_{\Delta p_s}$	Straight-through static pressure change through vent shaft $C'_{\Delta p_s} = \dfrac{p_o - p_\infty}{\frac{1}{2}\rho V_{v_e}^{\;2}}$
C_f	Tunnel wall friction coefficient $C_f = \dfrac{\tau_W}{\frac{1}{2}\rho V^2}$
D	Tunnel diameters
G_i^*	Geometry of Vent Shaft inlet
H	Height of Station
ΔH_s , ΔH_i , ΔH_t , ΔH_a	Total head losses (see definitions of $C_{\Delta H_s}$, $C_{\Delta H_i}$, $C_{\Delta H_t}$, $C_{\Delta H_a}$)
j	an integer
L	Length of tunnel
L_s	Length of station
p_1	Pressure upstream of vent shaft
p_2	Pressure downstream of vent shaft
p_o	Plenum (stagnation) pressure
p_∞	Atmospheric pressure
Δp	Pressure difference
R	Radius of tube
	Radial coordinate

Re	Reynold's number $= \frac{\rho V_1 D}{\mu}$
V_1	Axial velocity upstream of vent
V_2	Axial velocity downstream of vent
V_v	Vent shaft flow velocity
V_{v_i}	Vent shaft flow velocity at vent inlet
V_{v_e}	Vent shaft flow velocity at vent exit
W	Station width
X	Axial coordinate along tunnel
Γ	Shape factor for fully developed pipe flow
ρ	Air mass density
μ	Air viscosity

Barred quantities refer to inflow into vent shaft. Such coefficients are normalized with velocity V_2. See pages 9 and 10 for definitions.

5. REFERENCES

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2. HUNSAKER, J. C. and B. G. RIGHTMIRE, Engineering Applications of Fluid Mechanics, 1947, McGraw-Hill Book Co., Inc.

3. SCHLICHTING, H., Boundary Layer Theory, 4th Edition, 1960, McGraw-Hill Book Co., Inc.

4. STREETER, V. L., Handbook of Fluid Dynamic, 1st Edition, 1961, McGraw-Hill Book Co., Inc.

5. Fan Engineering, Buffalo Forge Company.

6. FIGURES

1. Theoretical model of flow past a vent shaft.
2. Flow into a Vent Shaft with "Straight-Through" inlet conditions.
3. Experimental characterization of Vent Shaft and Station performance according to equations 4 and 7.
4. Transition section.
5. Flow in stations.
6. 50' VST Facility schematic.
7. Replica Vent Shaft "in situ".
8. VST Facility with station installed.
9. Method of Determining $C_{\Delta H_s}$
10. VST Facility with Vent Shaft test section installed.

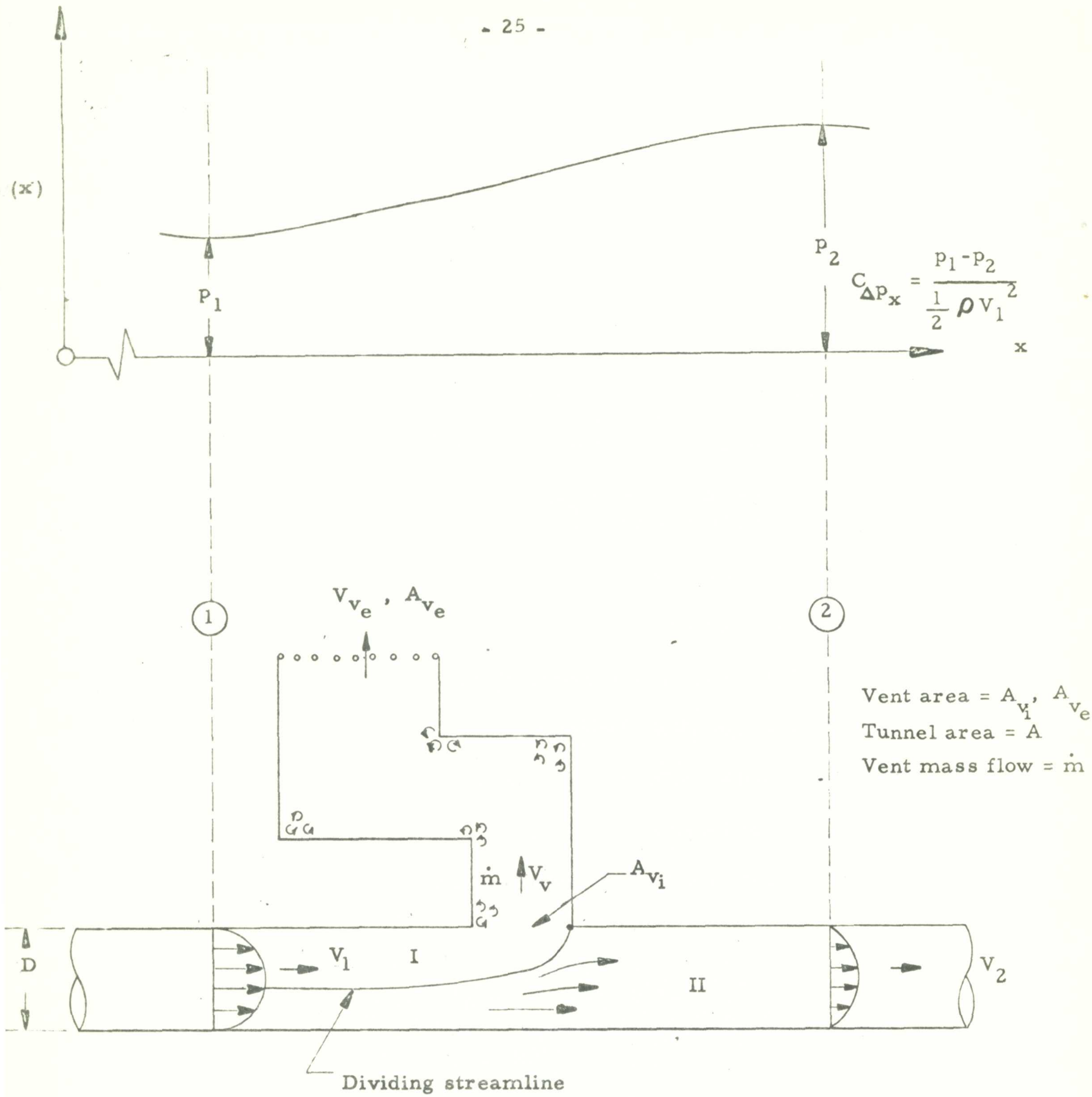
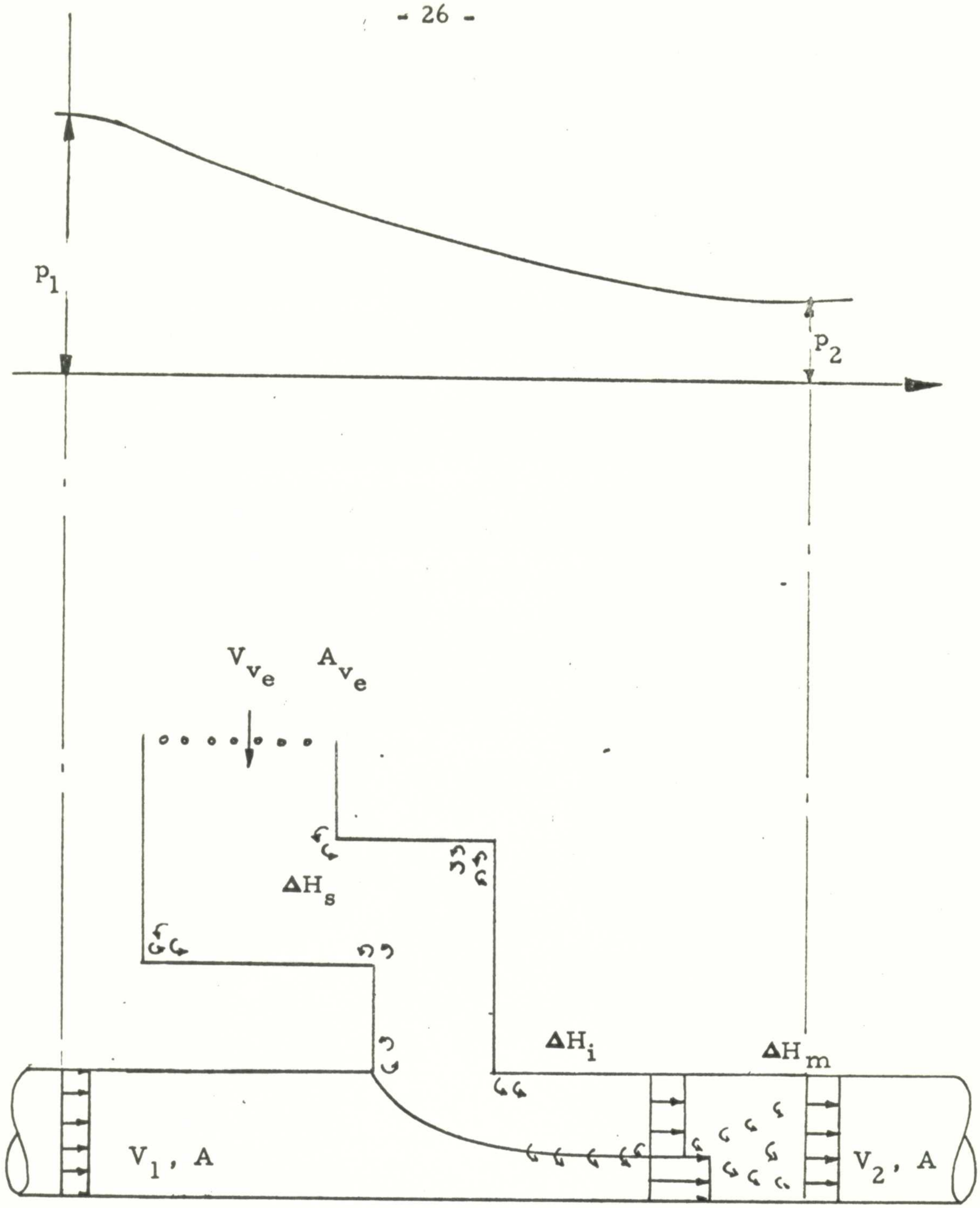


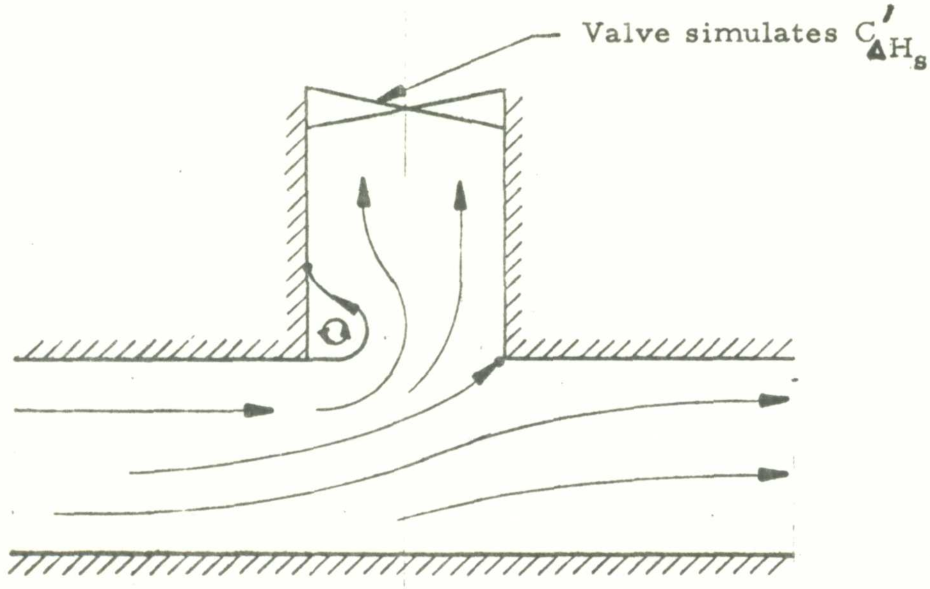
Figure (1a)

Theoretical model of flow past a vent shaft. (Outflow)

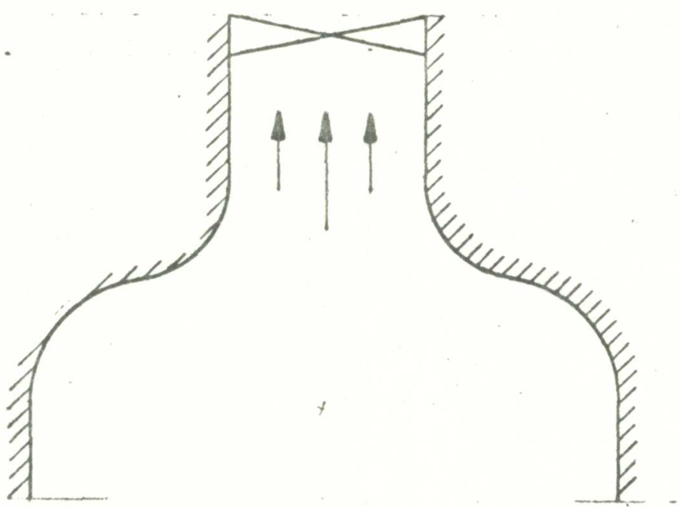


Theoretical Model of the Flow Past in Vent Shaft (Inflow)

Figure (1b)



Flow into a Vent Shaft
"IN SITU"



Flow into a Vent Shaft
with "straight-through"
inlet conditions.

Figure (2)

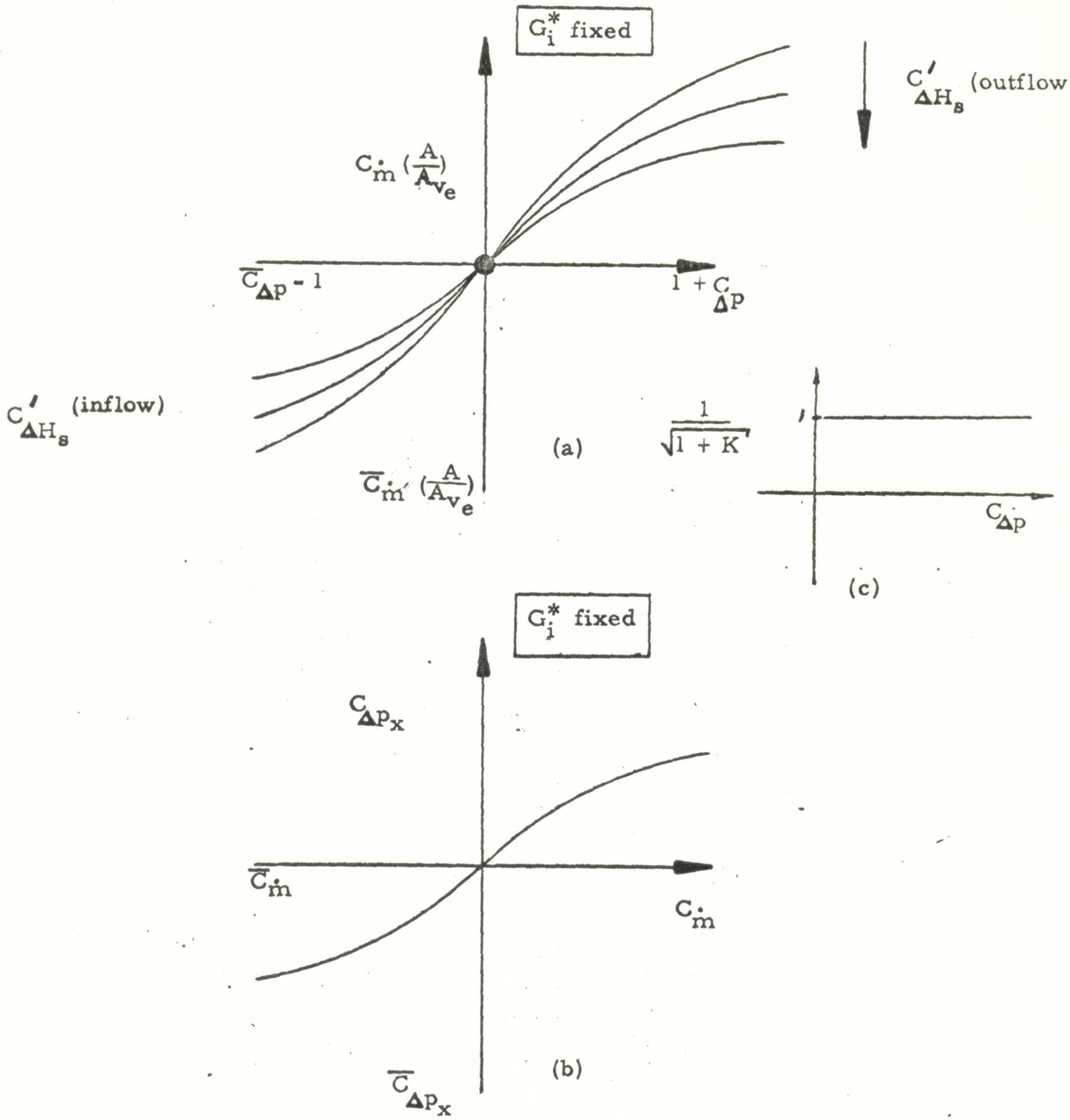


Figure (3)

Experimental characterization of vent shaft and station performance according to equations (4) and (7).

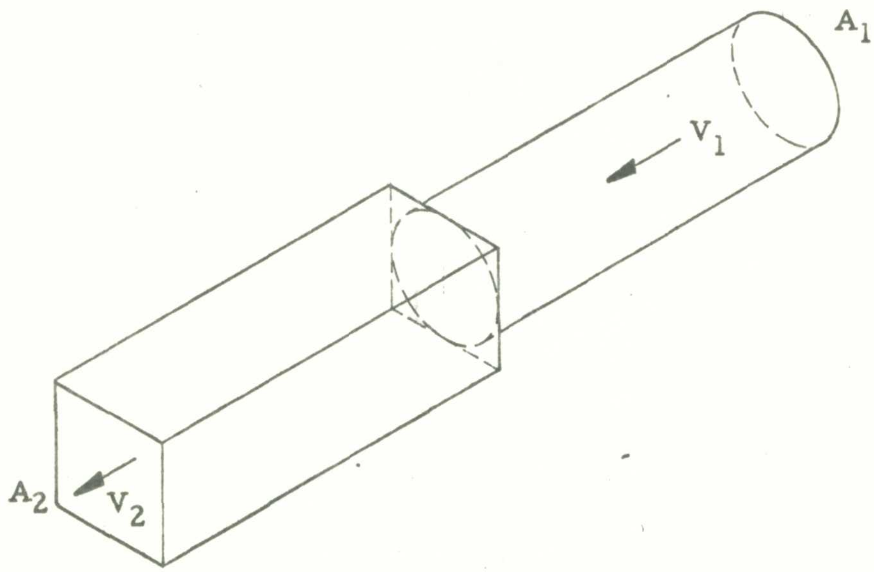


FIGURE (4)

TRANSITION SECTION

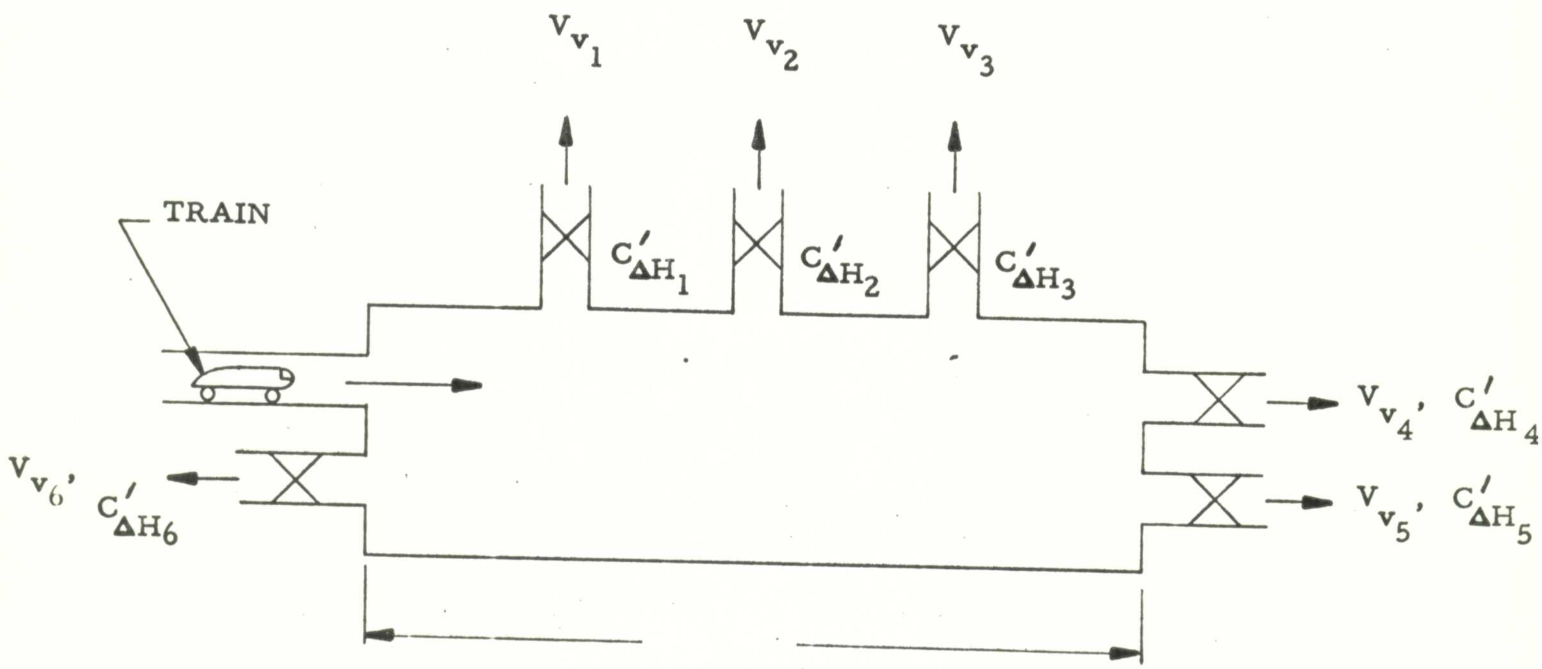
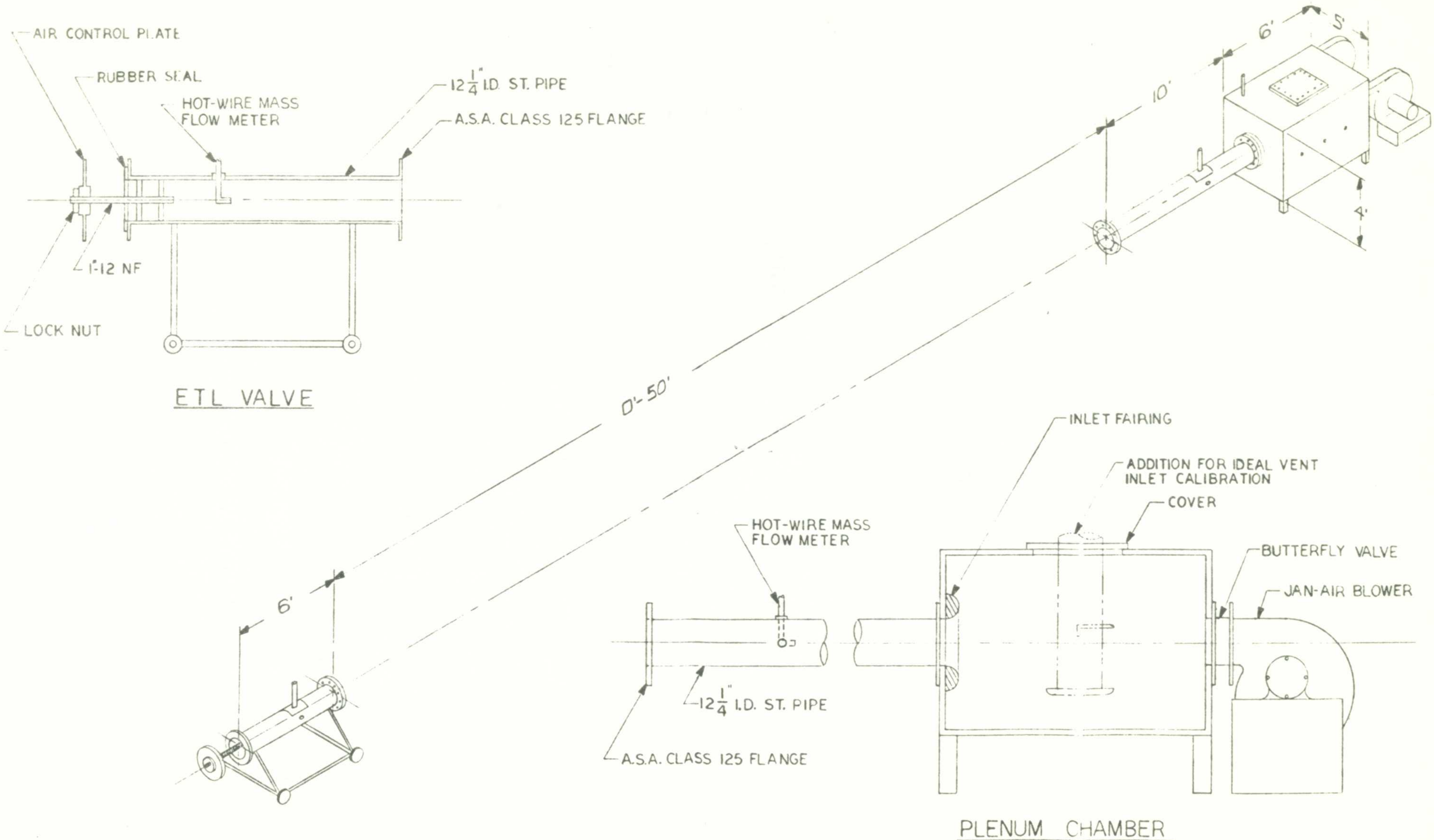


FIGURE (5)

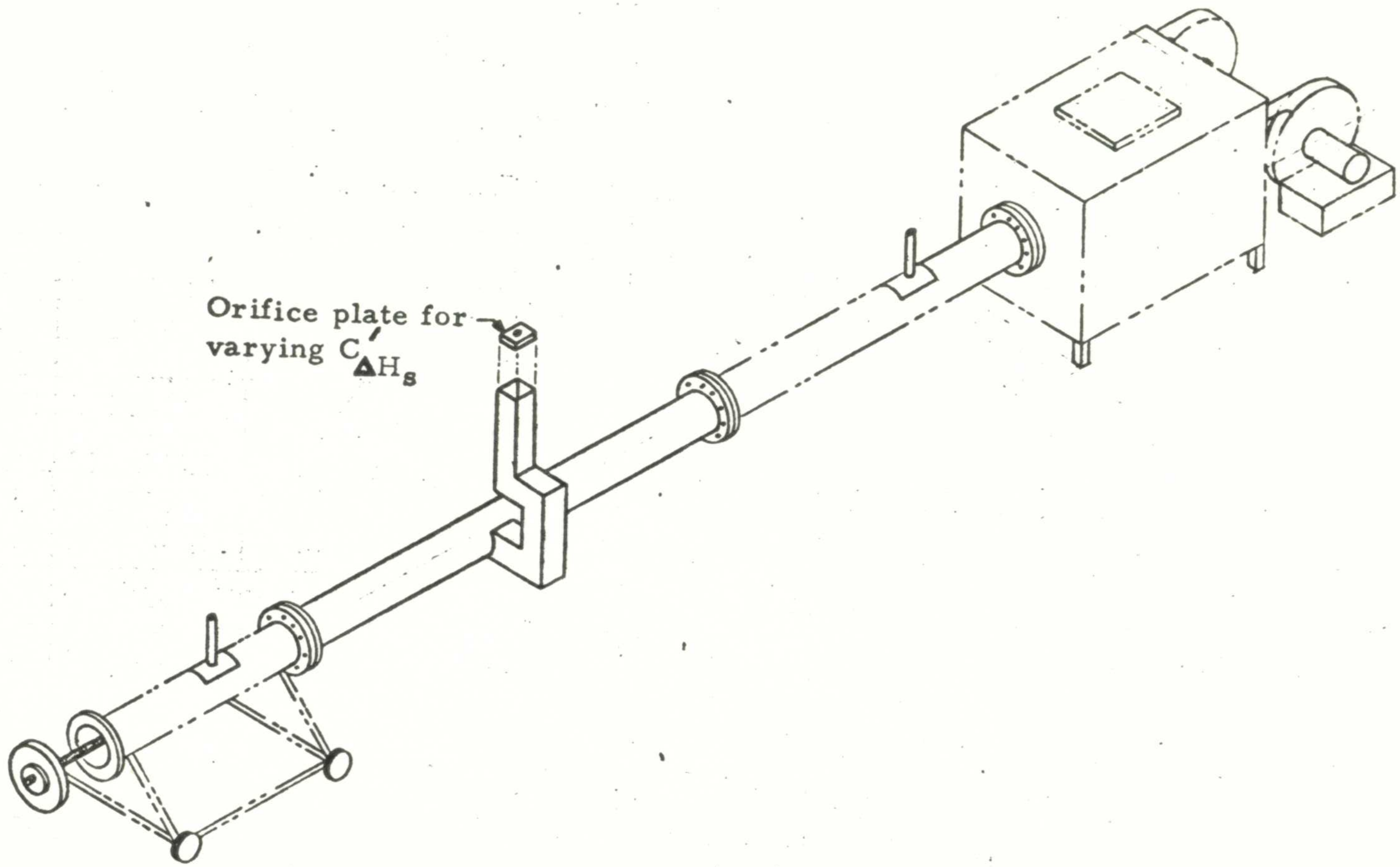
FLOW IN STATIONS



A

FIGURE (6)
THE 50' V.S.T. FACILITY
SCHEMATIC

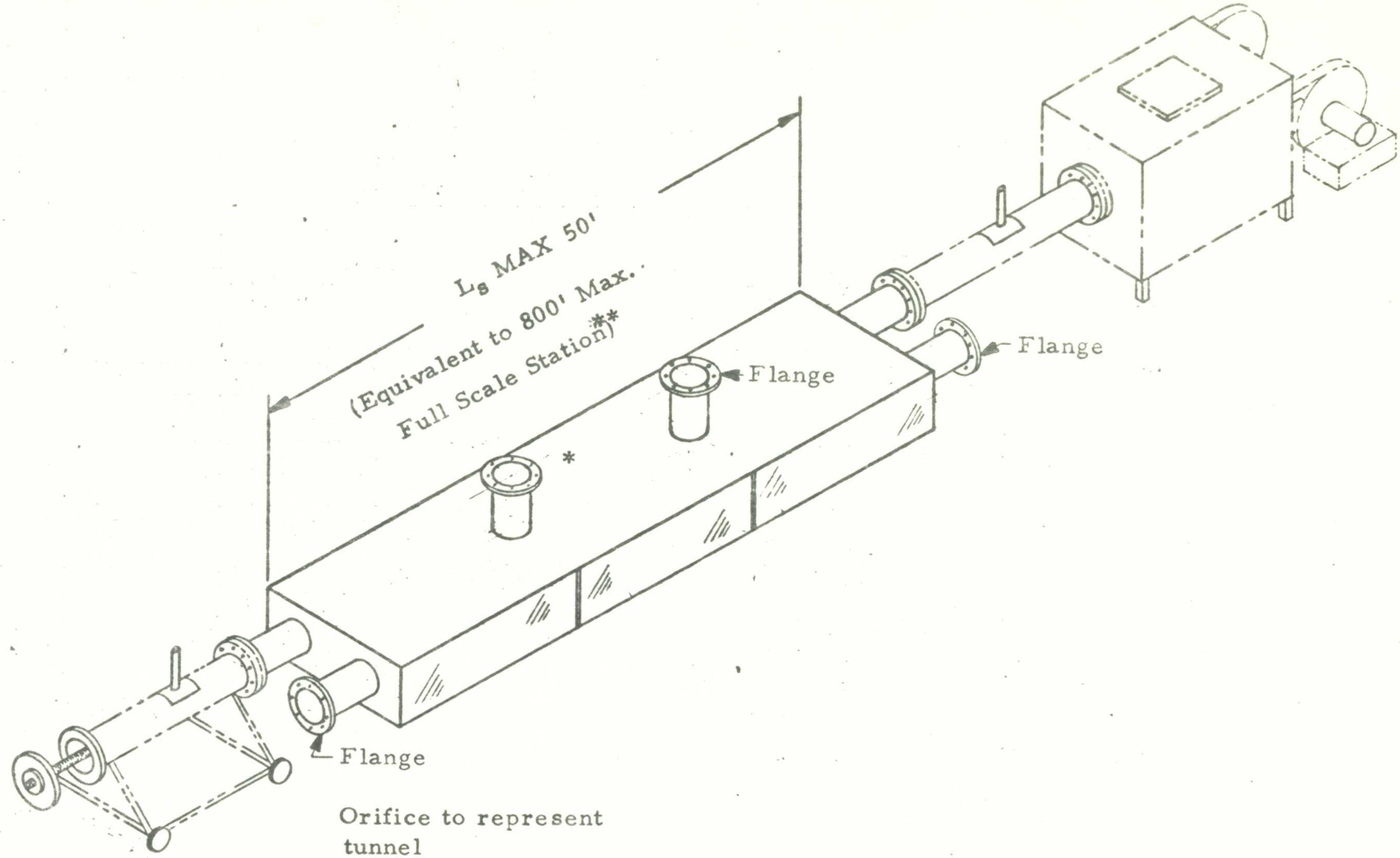
B



<u>Figure (7)</u>

Replica Vent Shaft "in situ"

(Schematic)



* Representative of typical station openings i.e., stairwells, vent shafts, etc.

** Either variable geometry or replica stations.

Figure (8)

VST Facility With Station Installed

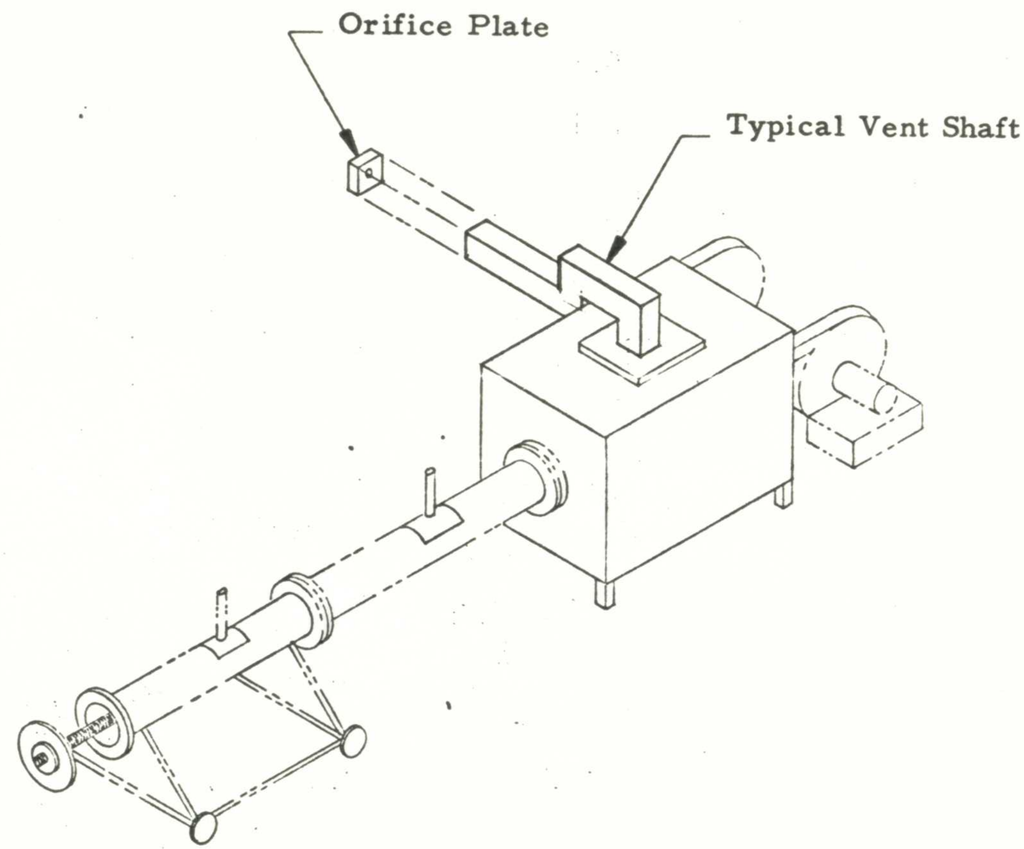


Figure (9)

Method of Determining $C'_{\Delta H_s}$

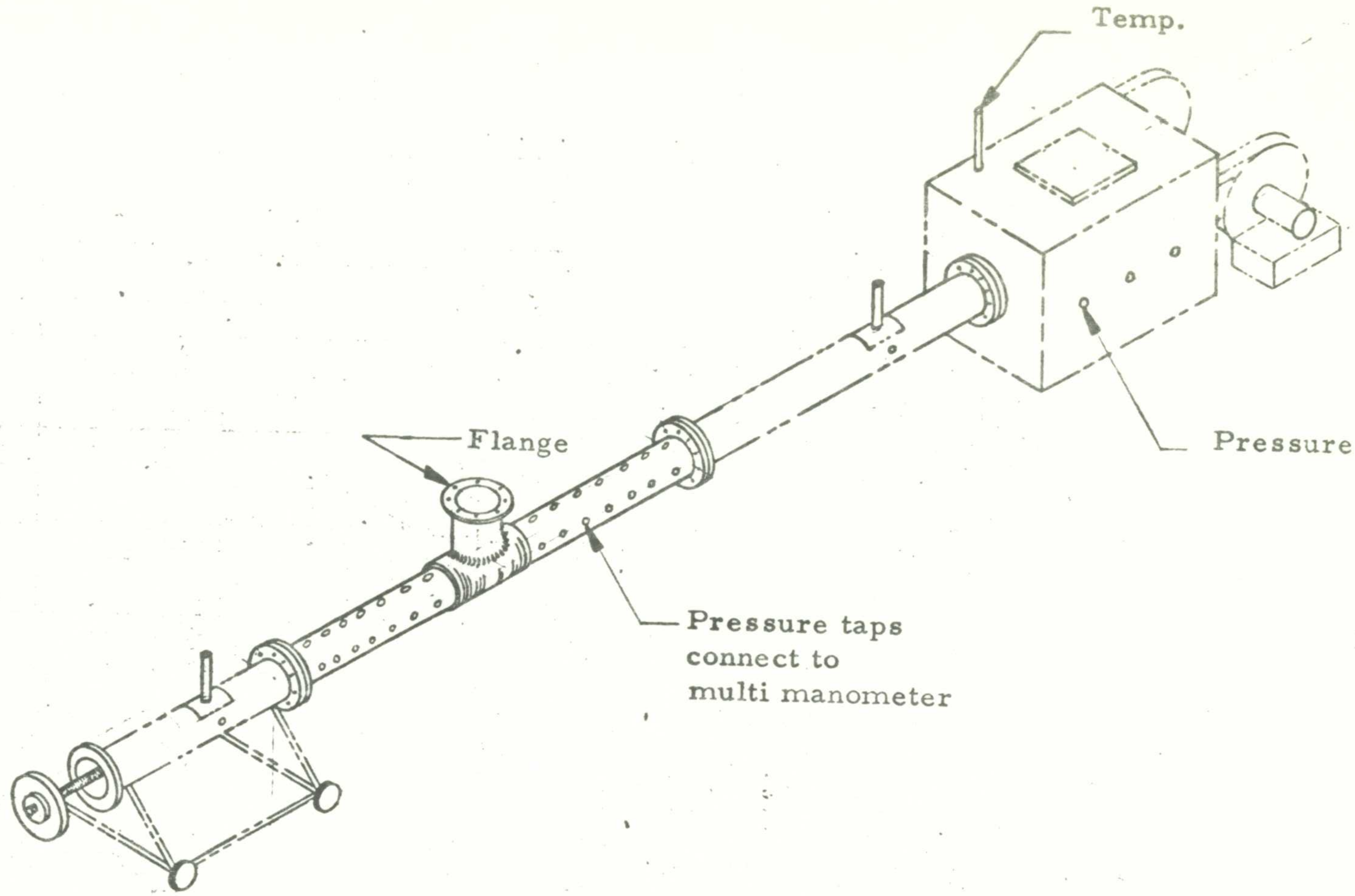


Figure (10)

VST Facility With Vent Shaft
Test Section Installed

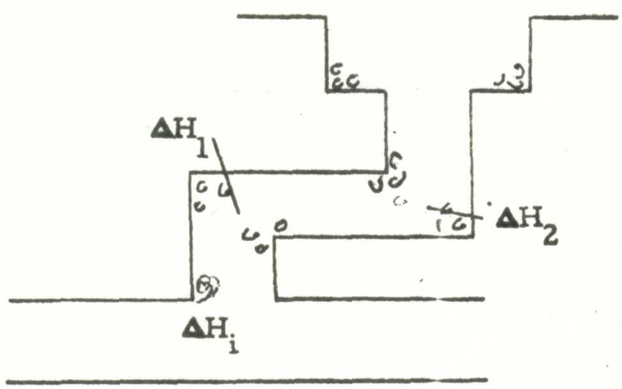
Appendix

7. APPENDICES

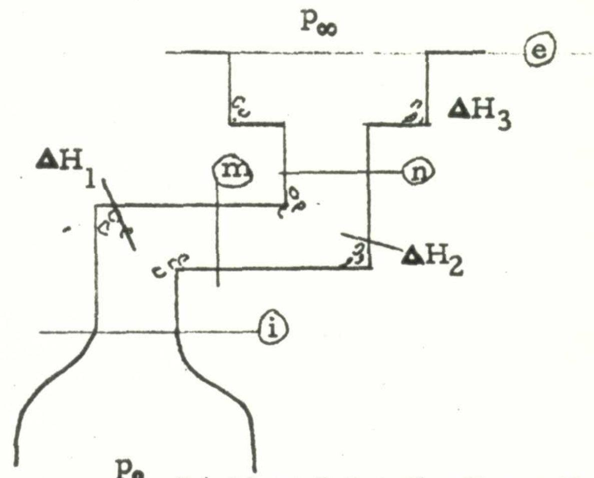
7.1 APPENDIX A

CALCULATION PROCEDURE FOR DETERMINING C_{H_s} (or C_{H_s}

If we assume that the vent shaft in question is supplied from a plenum chamber at stagnation pressure p (zero velocity) through an ideal inlet (no total head losses in the inlet), then C_{H_s} may be simply calculated in many cases using the steady Bernoulli equation and standard hand-book data for the loss coefficients.* The following example will serve to clarify the procedure.



(a) Actual "In Situ" Vent Shaft



(b) Ideal Inlet Configuration

Referring to Figure (b) above, the total head loss in the shaft is

$$\Delta H_s = \Delta H_i + \Delta H_2 + \Delta H_3$$

i.e.,

$$C'_{\Delta H_s} = \frac{\Delta H_s}{\frac{1}{2}\rho V_{v_e}^2} = \frac{\Delta H_1 + \Delta H_2 + \Delta H_3}{\frac{1}{2}\rho V_{v_e}^2}$$

---

* In the case of mezzanines, dividing junctions, etc., this process may yield less reliable results.

$$= \frac{\Delta H_1}{\frac{1}{2}\rho V_{v_i}^2} \left(\frac{V_{v_i}}{V_{v_e}}\right)^2 + \frac{\Delta H_2}{\frac{1}{2}\rho V_{v_m}^2} \left(\frac{V_{v_m}}{V_{v_e}}\right)^2 + \frac{\Delta H_3}{\frac{1}{2}\rho V_{v_n}^2} \left(\frac{V_{v_n}}{V_{v_e}}\right)^2$$

(Turn #1) (Turn #2) (Expansion)

But from continuity,

$$\frac{V_{v_i}}{V_{v_e}} = \frac{A_{v_e}}{A_{v_i}}, \quad \frac{V_{v_m}}{V_{v_e}} = \frac{A_{v_e}}{A_{v_m}}, \quad \frac{V_{v_n}}{V_{v_e}} = \frac{A_{v_e}}{A_{v_n}}$$

Defining for now

$$C_{\Delta H_1} = \frac{\Delta H_1}{\frac{1}{2}\rho V_{v_i}^2}, \quad C_{\Delta H_2} = \frac{\Delta H_2}{\frac{1}{2}\rho V_{v_m}^2}, \quad C_{\Delta H_3} = \frac{\Delta H_3}{\frac{1}{2}\rho V_{v_n}^2}$$

we obtain

$$C'_{\Delta H_s} = C_{\Delta H_1} \left(\frac{A_{v_e}}{A_{v_i}}\right)^2 + C_{\Delta H_2} \left(\frac{A_{v_e}}{A_{v_m}}\right)^2 + C_{\Delta H_3} \left(\frac{A_{v_e}}{A_{v_n}}\right)^2$$

Take for example

$$\frac{A_{v_e}}{A_{v_i}} = 2, \quad \frac{A_{v_e}}{A_{v_m}} = 2, \quad \frac{A_{v_e}}{A_{v_n}} = 2$$

(i.e., constant area duct until the expansion where the area suddenly doubles)

$$C'_{\Delta H_s} = (2)^2 \left[C_{\Delta H_1} + C_{\Delta H_2} + C_{\Delta H_3}\right]$$

Now, for a mitered right-angle turn, $C_{\Delta H} = 1.15$ [5], and for a sudden expansion, $C_{\Delta H} = 0.88$ [4], so that

$$C'_{\Delta H_s} = 4\ (1.15 + 1.15 + .88) = 3.18 \times 4 = \underline{\underline{12.72}}$$

or,
$$C_{\Delta H_s} = C'_{\Delta H_s} \left(\frac{A_{v_i}}{A_{v_e}}\right)^2 = \underline{\underline{3.18}}$$

The total static pressure change across the shaft is equal to the sum of the losses plus the kinetic energy flux, i.e.,

$$C_{\Delta p_s} = \frac{p_o - p_\infty}{\frac{1}{2}\rho V_{v_i}^2} \cdot \frac{\frac{1}{2}\rho V_{v_e}^2}{\frac{1}{2}\rho V_{v_i}^2} + C_{\Delta H_s}$$

$$= \left(\frac{A_{v_i}}{A_{v_e}}\right)^2 + C_{\Delta H_s} = \frac{1}{4} + C_{\Delta H_s} = \underline{\underline{3.43}}$$

Similarly, using the coefficients based on vent exit velocity gives

$$C'_{\Delta p_s} = \frac{p_o - p_\infty}{\frac{1}{2}\rho V_{v_e}^2} = 1 + C'_{\Delta H_s} = \underline{\underline{13.72}}$$

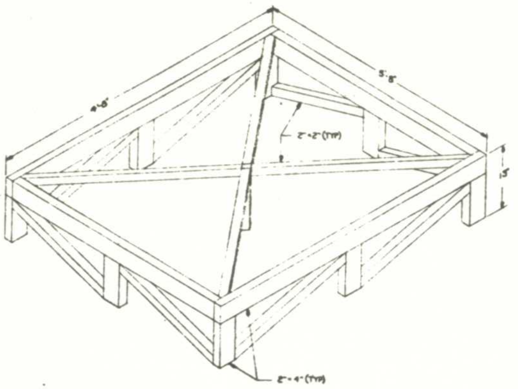
The choice of whether to use coefficients based on inlet velocity ($C_{\Delta H_s}$, $C_{\Delta p_s}$) or exit velocity ($C'_{\Delta H_s}$, $C'_{\Delta p_s}$) will depend upon the particular vent shaft geometry.

7.2 APPENDIX B

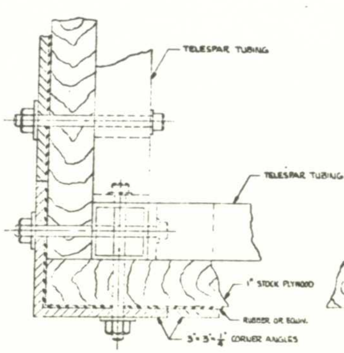
Design calculations and detailed drawings of the VST Facility.

Reference Drawings

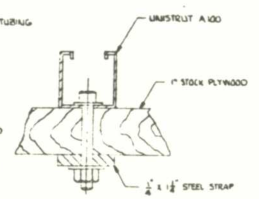
7020-3-1001	VST Assembly
1002	VST Plenum Chamber
1003	VST Pipe and Fittings



DETAIL -113 PLENUM STAND
MAT'L: WOOD

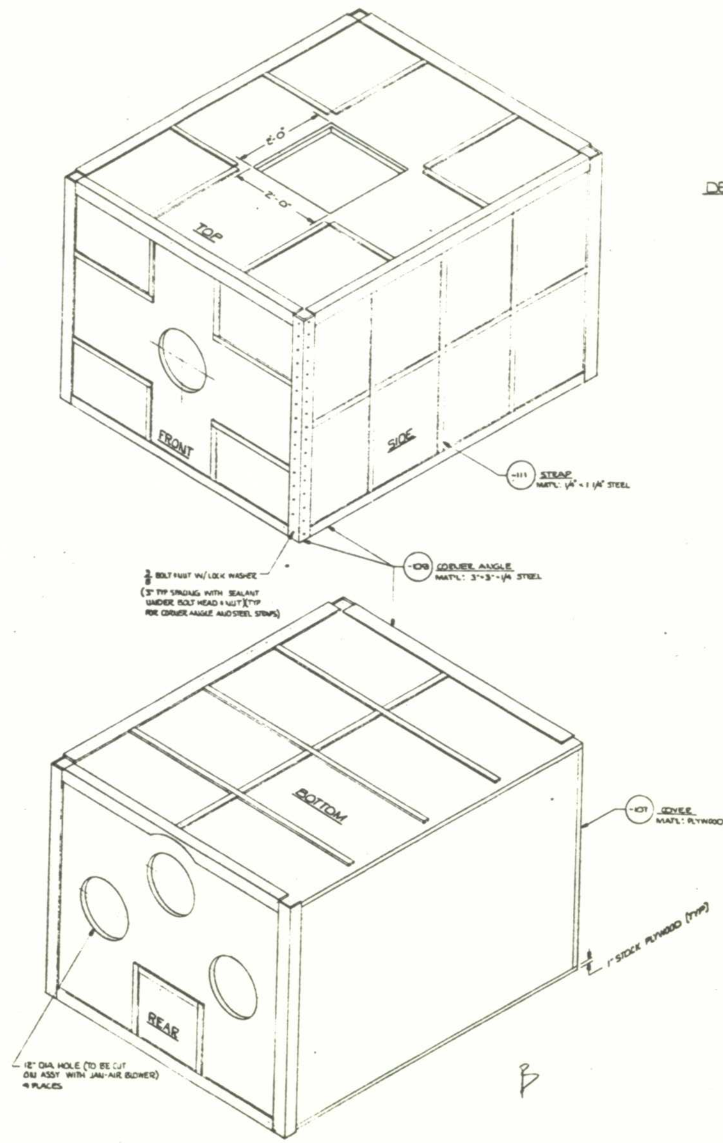


TYP SECTION LOOKING ON AT CORNER



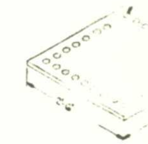
TYP SECTION FOR UNISTRUT

A

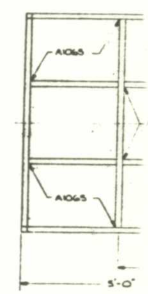


B

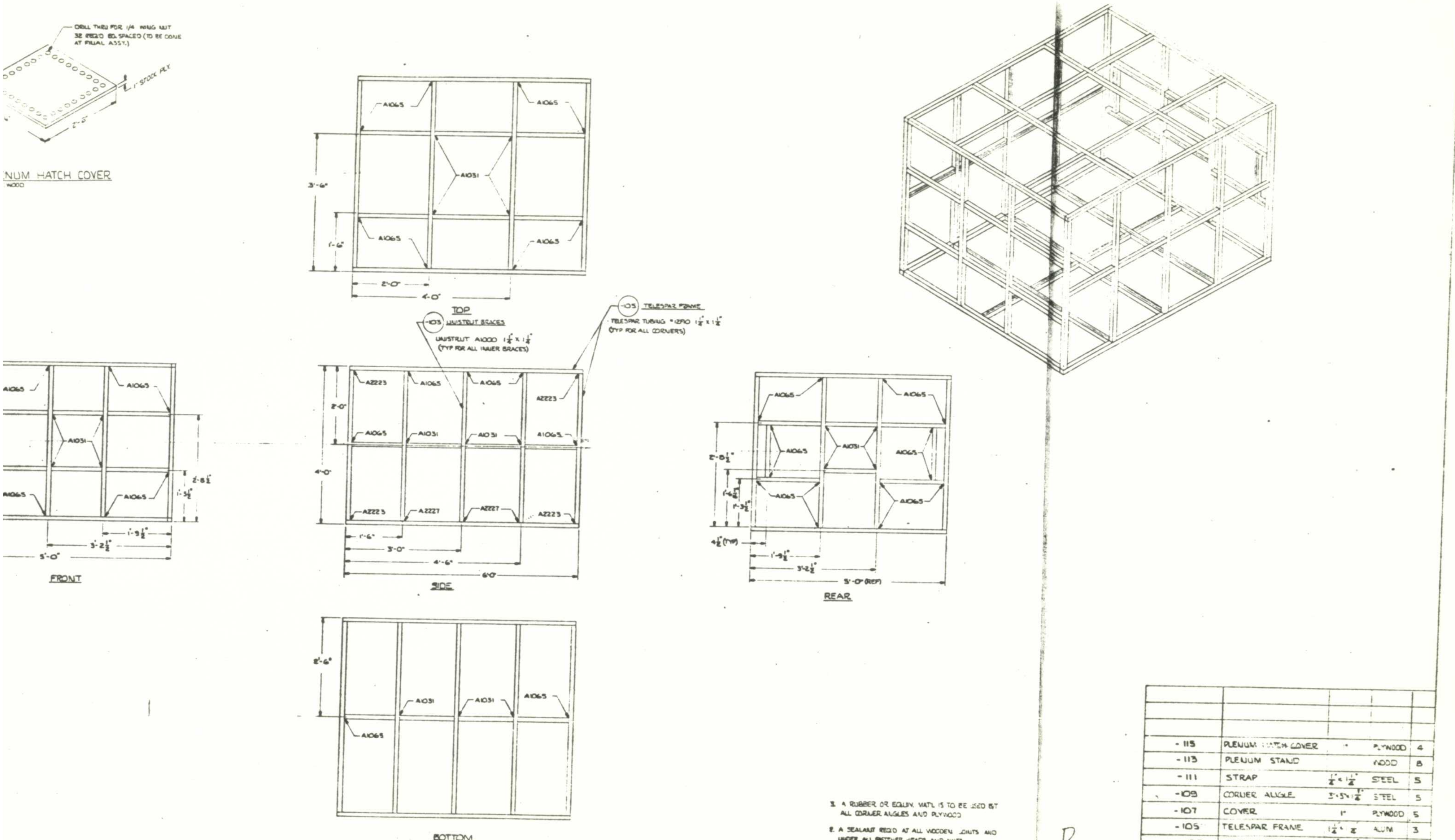
DETAIL - 101 PLENUM CHAMBER ASSY



DETAIL -115 PLENUM HATCH
MAT'L: WOOD



FR



NOTES:

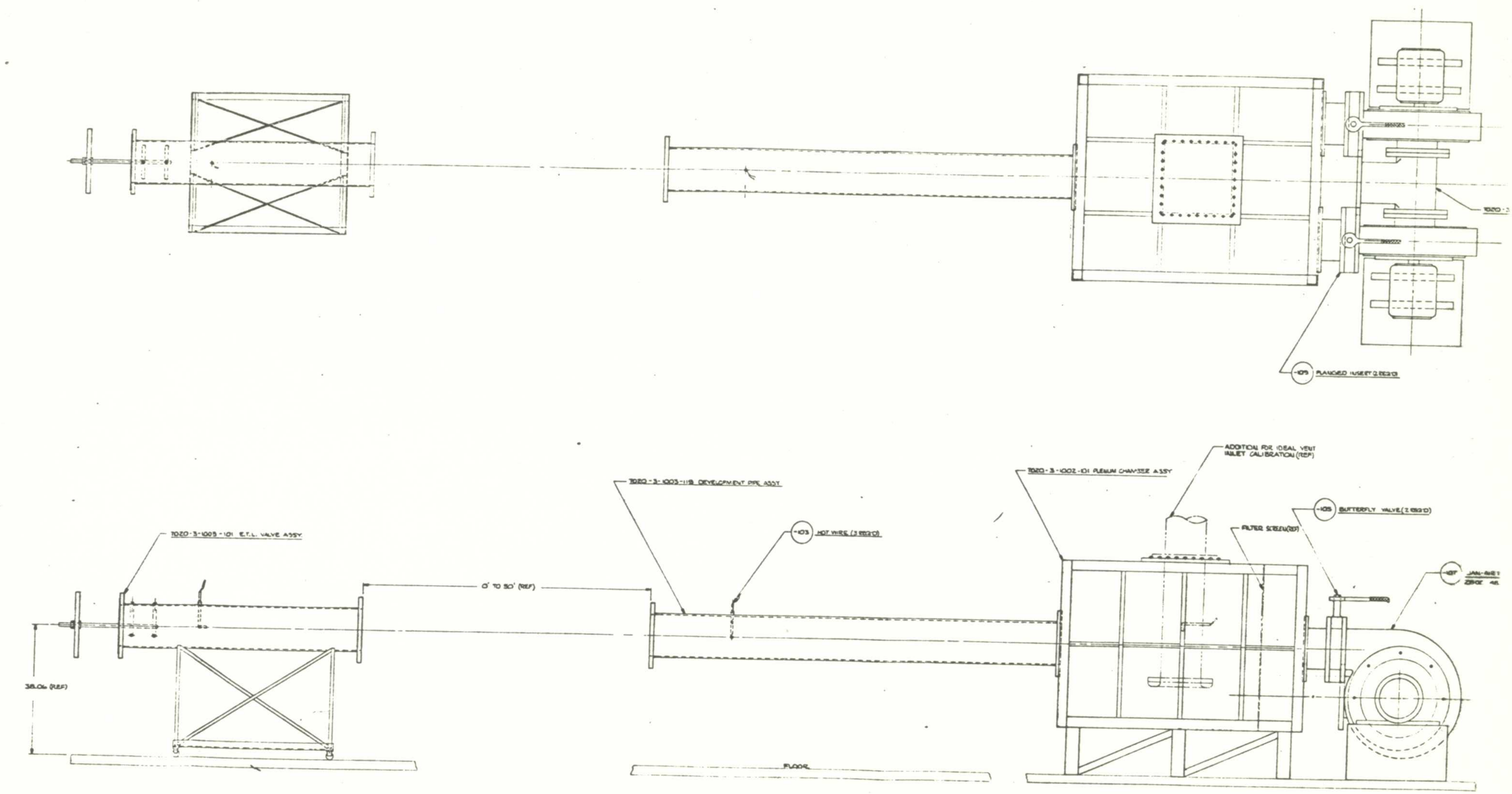
3. A RUBBER OR EQUIV. MAT'L IS TO BE USED B/T ALL CORNER ANGLES AND PLYWOOD
2. A SEALANT REQ'D AT ALL WOODEN JOINTS AND UNDER ALL FASTENER HEADS AND NUTS
1. LOCK TYPE WASHER TO BE USED UNDER ALL BOLT HEADS AND NUTS

PART NO	PART NAME	STOCK SIZE	MATERIAL	ZONE
-115	PLENUM HATCH COVER	1"	PLYWOOD	4
-113	PLENUM STAND		WOOD	8
-111	STRAP	¼" x 1½"	STEEL	5
-109	CORNER ANGLE	3" x 3" x ¼"	STEEL	5
-107	COVER	1"	PLYWOOD	5
-105	TELESPAR FRAME	1¼" x ¼"	ALUM	3
-103	UNISTRUT BRACE	1¼" x ¼"	ALUM	3
-101	PLENUM CHAMBER ASSY			6

ENGR: BAXTER 12-15-81 CHK: APP'D: SCALE: 10=1"

SHEET NAME: V.S.T. PLENUM CHAMBER — SHT 1 OF 1

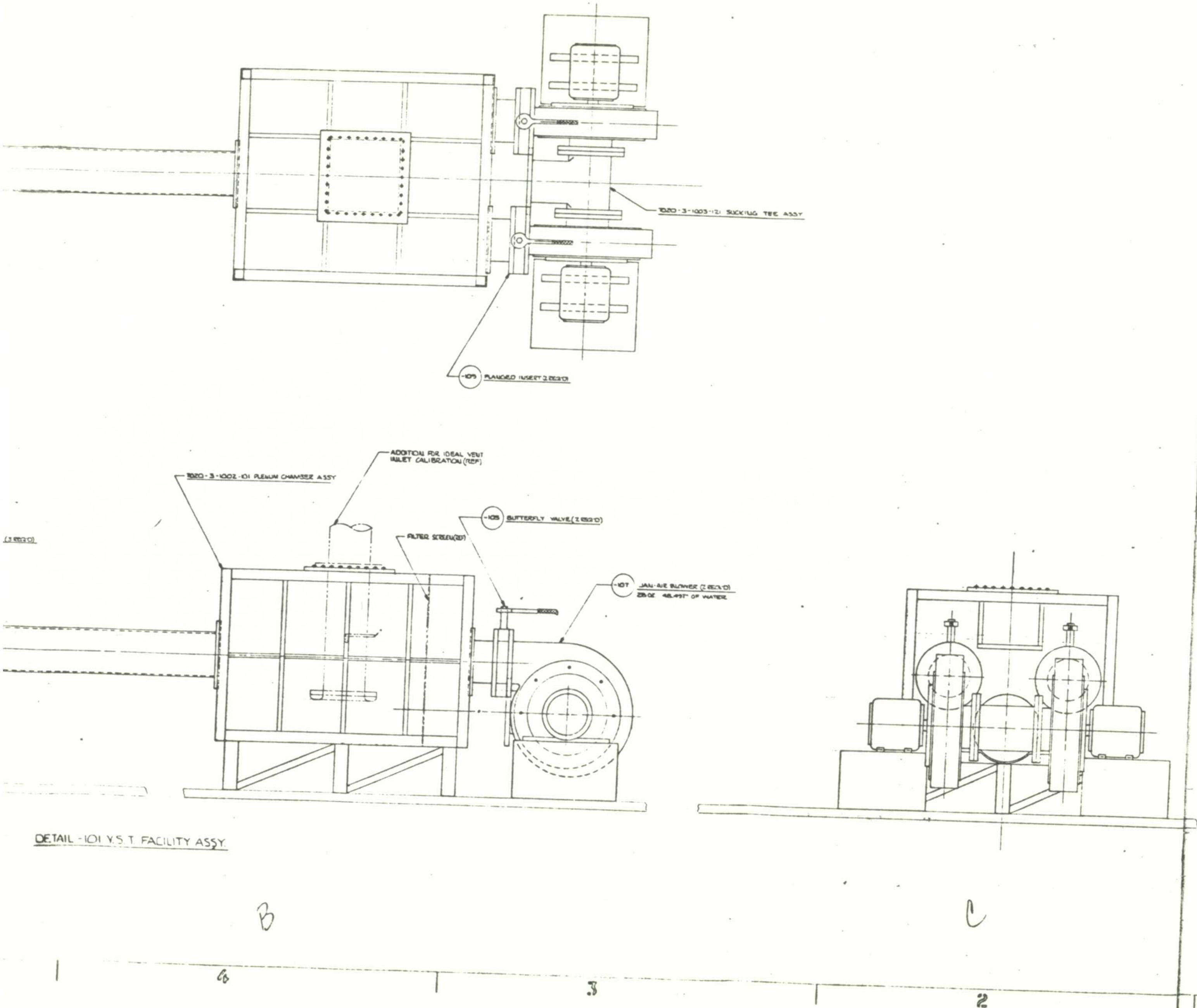
D.S.I. – AEROSPACE TECHNOLOGY — DWG NO 7020-3-1002



DETAIL -101 Y.S.T. FACILITY ASSY.

A

B



7020-3-1003-121	SUCKING TEE	12"	STEEL
7020-3-1003-119	DEVELOPMENT PIPE ASSY	12.25-0-10 PIPE	STEEL
7020-3-1003-101	E.T.L. VALVE ASSY	12.25-0-6' PIPE	STEEL
7020-3-1002-101	PLENUM CHAMBER ASSY	4-5-6	UNISTRUT-REED SEE.
-109	FLANGED INSERT		STEEL
-107	JAN AIR BLOWER	28.0Z 48.45" OF WATER	
-105	BUTTERFLY VALVE	12"	
-103	HOT WIRE		
-101	V.S.T. FACILITY ASSY.		
PART NO	PART NAME	STOCK SIZE	MATERIAL

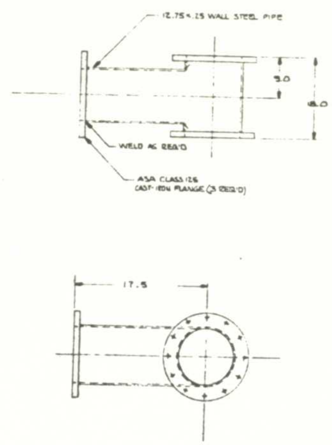
ENGR: BAXTER 1-4-71 APP'D SCALE

SHEET NAME: V.S.T. FACILITY SHT 1 OF

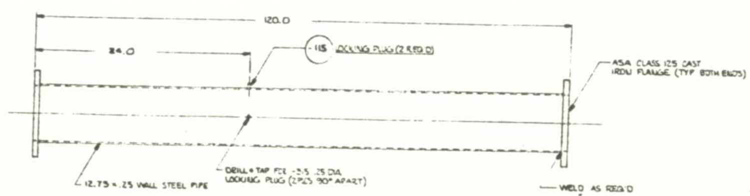
D.S.I. - AEROSPACE TECHNOLOGY

DWG NO 7020-3-1001

1

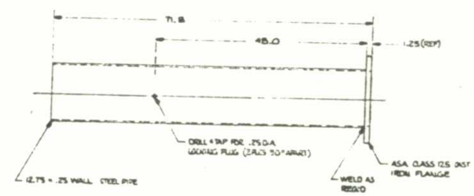


DETAIL - 121 SUCKING TEE ASSY (1 REQ'D)



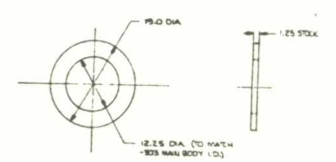
DETAIL - 119 DEVELOPMENT PIPE ASSY (1 REQ'D)

A



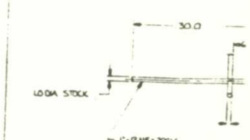
DETAIL - 103 MAIN BODY 1 REQ'D

DETAIL - 109
MAT'L: STEEL OR EQ.

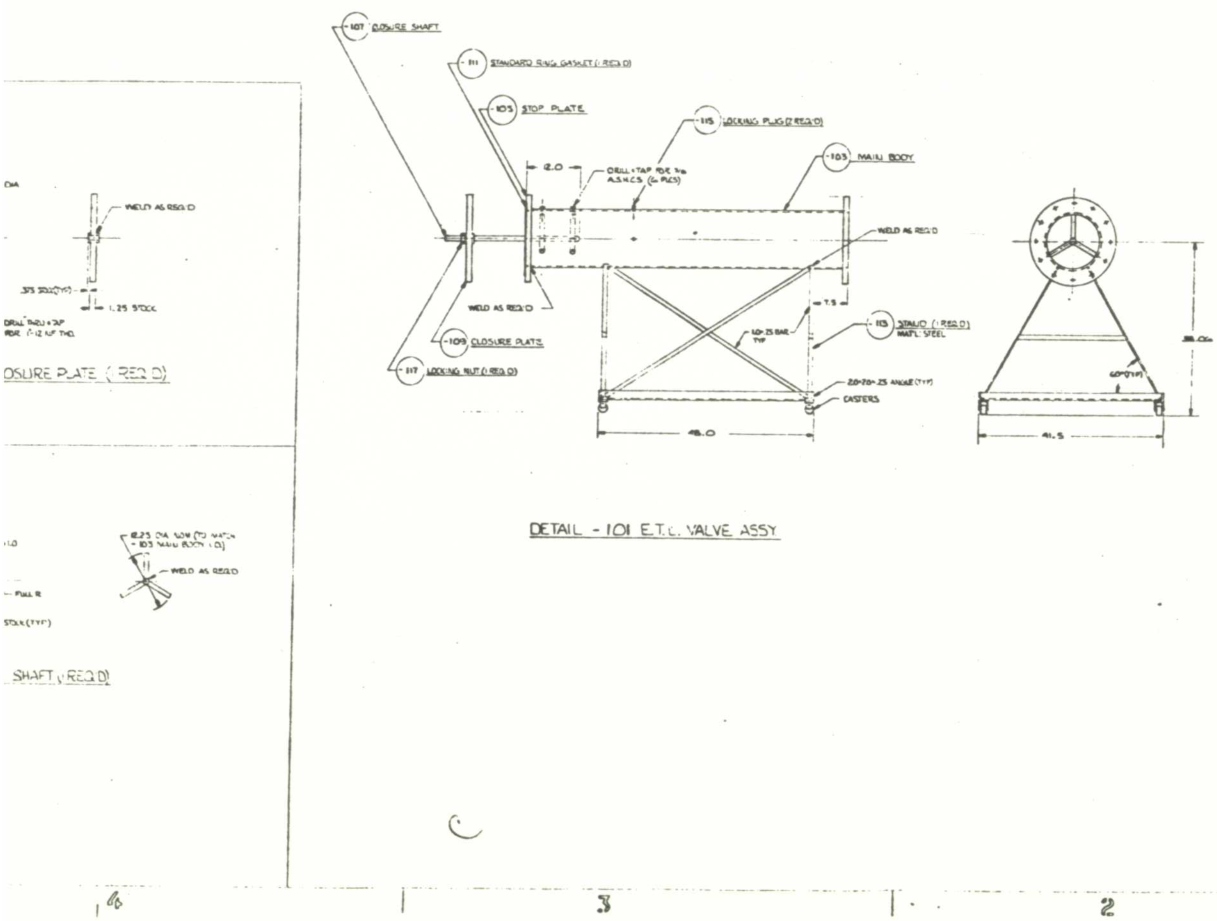


DETAIL - 105 STOP PLATE (1 REQ'D)
MAT'L: STEEL OR EQUIV

B



DETAIL - 107 CLOS
MAT'L: STEEL OR EQUIV



-121	SUCKING TEE			7
-119	DEVELOPMENT PIPE ASSY			7
-117	LOCKING NUT			3
-115	LOCKING PLUG			3+7
-113	STAND		STEEL	3
-111	STD RING GASKET		RUBBER	3
-109	CLOSURE PLATE	[illegible]	STEEL	4
-107	CLOSURE SHAFT	[illegible]	STEEL	4
-105	STOP PLATE	[illegible]	STEEL	5
-103	MAIN BODY	[illegible]	STEEL	5
-101	E.T.L. VALVE ASSY			3
PART NO.	PART NAME			ZONE

V.S.T. PIPE AND FITTINGS

D.S.I. — AEROSPACE TECHNOLOGY

DWG. NO. 7120-3-1003

7.3 APPENDIX C

BLOWER REQUIREMENTS

A blower capable of providing the necessary volume flow rate and required pressure is sized in the following manner.

The power required is expressed by

$$\underline{P} = \frac{1}{2}\rho V^3 A + 4\, C_f \frac{L}{D} A \frac{1}{2}\rho V^3$$

Kinetic energy flux	Power losses due to wall friction

Assume

$V = 100$ ft/sec [which for 75% Blockage is approx. 100 mph for the train speed]

$A = \pi/4\,(1)^2 = .786$ [internal area of scaled tunnel]

$C_f = .02$ [rough pipe gives maximum flexibility]

$L/D \doteq 300$ [equivalent to a one mile long tunnel]

Then,

$$\underline{P} = \frac{1}{2}\rho V^3 A\,[1 + 4\,C_f\,L/D]$$

$$= .5(.0023)\,(10^6)\,(.786)\,[1 + 4\,(.02)\,(300)]$$

$$= 9.03 \times 10^2\,[25]$$

$$\underline{P} = \frac{2.25 \times 10^3}{550} = \boxed{41 \text{ hp}}$$

$$Q = VA \text{ cfs}$$

$$= 100\,(.786) = 78.6 \text{ cfs}$$

$$Q = \boxed{4720 \text{ cfm}}$$

$$p = 4\,C_f\ {}^{L}/_{D}\ A\ \frac{1}{2}\ V^2$$

$$= 4\ (.02)\ (300)\ (.786)\ (.5)\ (.0023)\ 10^4$$

$$= (.08)\ (150)\ (.00181)\ X\ 10^4$$

$$p = 217/144 = 1.51 \text{ psig}$$

SUMMARY

P	=	41 hp
Q	=	4700 Cfm
p	=	1.51 psig

7.4 APPENDIX D

VENT SHAFT EVALUATION AND RECOMMENDATIONS

Submitted to

INSTITUTE FOR RAPID TRANSIT

and

TECHNICAL COMMITTEE for

the ASSOCIATED ENGINEERS

by

AEROSPACE TECHNOLOGY

Division of Developmental Sciences, Inc.

January 15, 1971

UT-290-SC-3001

INTRODUCTION

As part of the Subway Environmental Research Project, several representative vent shafts need to be selected for use in the SAT facility. In order to complete the selection process it has been necessary to aerodynamically characterize Vent Shafts in terms of rational parameters. Unfortunately little quantitative information is available regarding the air flow properties of subway vent shafts. Therefore, DSI-AT undertook the study of these properties and designed a unique test facility to obtain the missing, yet necessary data. The VST facility will supply experimentally determined parameters which will serve as important inputs to the theoretical computer analysis, yield a better understanding of vent shafts in general for design purposes, specifically in regard to inlets, and will provide needed guidance for effective experimental work in the SAT facility.

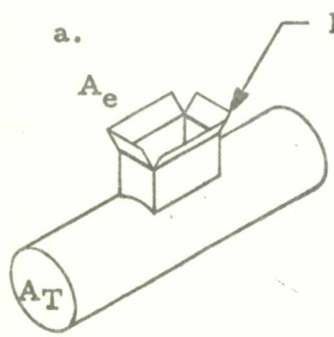
In this program, as in any valid research project, it is important to review existing Vent Shafts and to determine, in terms of the rationally derived parameters, their range of values. In this context the Kaiser Engineers were asked to study the various drawings furnished by the operating properties and to summarize geometrical data and pressure drop coefficient calculations in tabular form. DSI-AT has reviewed the KE data package and has held discussions with KE concerning the calculations, handbook data differences and recommended vent shafts for the study.

RECOMMENDATIONS

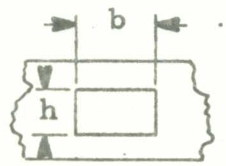
The following three Vent Shafts are suggested for study and testing in the VST facility. In each case the vent shaft configuration, parameters to be varied and their range, and rationale for recommending the study of this particular Vent Shaft are cited.

1. CONTROL VENT SHAFT AND VARIABLE MITRE TURN

a.



Configuration



Tunnel cut away looking up

Aspect Ratio: $b/H = 1/2, 1, 5, 10$

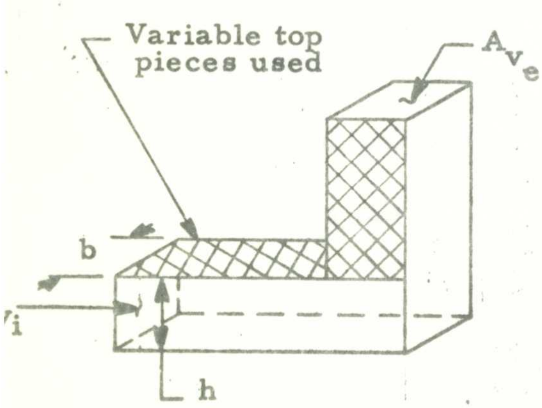
Area Ratio: $A_{vi}/A_T = 1/4, 1/2, 1, 2$
(Inlet)

Head Loss: $C_{\Delta H_s} = 0, 1, 3, 5, 10$
(straight-thru)

Area Ratio: $A_{ve}/A_T = 1/2, 1, 2, 5$
(Exit)

RATIONALE

1. Allows verification of analysis characterizing vent shafts.
2. Presents an opportunity to evaluate semi-empirically $C_{\Delta H_i}$, i.e., inlet loss.
3. Representative of many existing vent shafts (e.g., Chicago, BART, SCRTD).



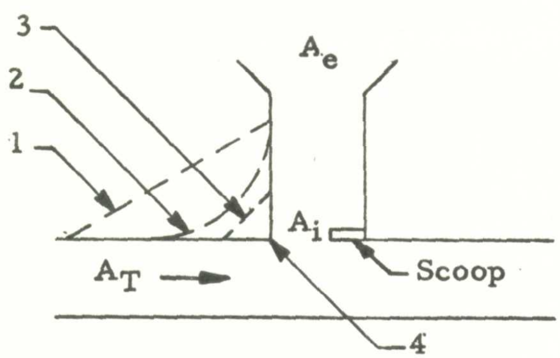
Area Ratio: $\dfrac{A_{v_e}}{A_{v_i}} = 1/4, 1/2, 3/4, 1, 2$

Aspect Ratio: $b/H = 1/2, 1, 5$

RATIONALE

1. Generally at a mitre turn the cross sectional area changes. When this occurs the appropriate velocity (area) for the turn is not a simple problem analytically to solve. Experimental investigation will establish the proper procedure for calculating the velocity and therefore the $C_{\Delta H_s}$ for the variable mitre turn.

II. VARIABLE INLET VENT SHAFT



Area Ratio: (Inlet) $A_{vi}/A_T = 1/2, 1, 2$

Area Ratio: $A_{ve}/A_T = 1/2, 1$

TURNS: ① Diffuser, ② Ideal ③ 45° ④ 90° ⑤ Scoop

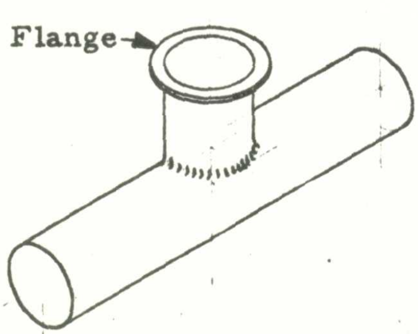
$C_{\Delta H_s}$: 0, 1, 5

RATIONALE

1. Inlet conditions can dominate the total vent shaft performance, therefore further investigation of shapes that will minimize the inlet losses need consideration.

2. Representative of many existing vent shafts.

III. SAT CALIBRATED SHAFT



$C_{\Delta H_s}$ = 0, 1, 5, 10,

Area Ratio: (Inlet) $A_{vi}/A_T = 1$

Area Ratio: (Exit) A_{ve}/A_T = Variable

Inlet Shape - circular - rounded corners

RATIONALE

1. At a first cut, a T section-shaped vent shaft from a fabrication cost and time basis is recommended. However, if the study of Vent Shafts I and II show that this configuration lacks flexibility, a more technically acceptable solution will be recommended.

TESTING

Efforts will be made in the VST model vent designs to minimize the man-hour expenditure to obtain the maximum amount of data. A test procedure and matrix will be submitted after the construction and calibration of the VST is completed.

7.5 APPENDIX E

STATION EVALUATION AND RECOMMENDATIONS

Submitted to

Institute for Rapid Transit

and

Associated Engineers

Technical Committee

by

AEROSPACE TECHNOLOGY

Division of Developmental Sciences, Inc.

February 10, 1971

UT-290-SC-3001

INTRODUCTION

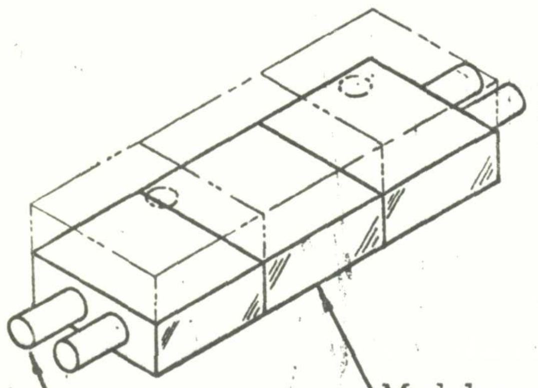
As part of the Subway Environmental Research Project, two representative stations need to be selected for use in the SAT facility. In order to complete the selection process it was necessary to aerodynamically characterize both stations and vent shafts in terms of rational parameters. This was done and is described in the VST Design Technical Milestone Report, DSI-AT Report No. 7020-3-1, January 1971.

Following the established pattern for evaluating Vent Shafts, Kaiser Engineers were asked to study the various drawings furnished by the operating properties and to summarize geometrical data and pressure drop coefficient calculations in the tabular form suggested by DSI-AT. DSI-AT Staff reviewed Section III of K. E.'s preliminary report on Single-Track Subway System Components, January 1971, and a subsequent transmittal including one Table of Station data. Based on these and PBQ & D's report of August 13, 1970, entitled "Preliminary Design Parameters", the following recommendations are made.

RECOMMENDATIONS

The following two Stations are suggested for study and testing in the VST facility. In each case the Station configuration, parameters to be varied and their range, and rationale for recommending the study of this particular Station are cited.

1. VARIABLE CONTROL STATION AND ENTRY MODELING



(Second tube is optional)

Length: 400, 600, 800 ft. (equiv.)*

Width: 60 ft.

Height: 15 ft. (without mez.)

Height: 30 ft. (with mez.)

Platform: (center) L = 350, 500, 700
W = 25 ft.

Mezzanine: $L_m' = L_s$
Blocked each end
20 ft.

Openings: 10-15% of square footage

Entrys: 4 Stairwell or escalators 100 and 200 ft.[2]

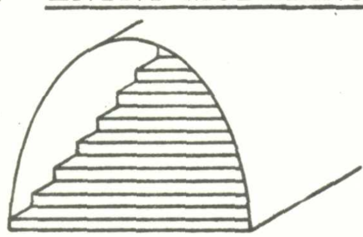
$C_{\Delta H_s}$ (entries): 0, 1/2, 1,2

RATIONALE

1. Building block geometry allows geometry to be rapidly and economically changed covering a wide range of representative station configurations.

2. Allows verification of analysis characterizing stations.

b. ENTRY MODELING



The $C_{\Delta H_s}$ for stairwells and escalators will be determined for several replica configurations.

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* All dimensions are listed in equivalent values, i.e., 1 ft. (actual) = 1/16 ft (SAT).

RATIONALE

1. Like the variable mitre-turn handbook data is sparse on stairwells and escalators, therefore a few tests are warranted to adequately characterize them to insure the black box technique is correct.

2. SAT CALIBRATED STATION

From the data obtained during the variable control station experiments, two fixed station configurations will be selected for use in the SAT facility. For example, one station might have a mezzanine the other might not.

TESTING

As with the Vent Shafts, the Station design will strive to minimize the effort and to maximize the amount of data acquired. A test procedure and text matrix will be submitted after the VST facility is calibrated.