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An Investigation of the Forced Ventilation in Containership Holds

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Fire Research
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
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Nomenclature

Ai	Airy function
C	Vapor concentration in air
C_o	Equilibrium vapor concentration of spill material
D	Fuel diffusivity in air
d	Slot half width
f	Function defined by eq. (10)
G	Grashof Number
g	Acceleration of gravity
h	Slot height
i	Unit vector in the x direction
j	Unit vector in the y direction
k	Unit vector in the z direction
ℓ_n	Length of slot "n"
m	Number of air changes per hour
$\dot{m}$	Local mass flux picked up, defined in eq. (73)
$\hat{M}$	Total mass flux picked up in a slot, defined in eq. (76)
N	Number of slots
n	Slot number
$\vec{n}$	Outward pointing normal to integration centure
p*	Thermodynamic pressure
p	Perturbation due to flow pressure
Pr	Prandtl Number
Q"	Slot source flow per unit area
Q_v	Total flow through end void
Q_n	Total flow through the nth slot
Q	Total flow drawn through hold

q	Normalized slot flow
Re	Reynolds Number = $md^2/\nu\tau$
Sc	Schmidt Number
T	Temperature
t	time
$\vec{u}$	Gas velocity
u	Gas velocity component parallel to x
v	Gas velocity component parallel to y
w	Gas velocity component parallel to z
x	Coordinate parallel to slot or void length
y	Coordinate parallel to slot or void height
Y	Dimensionless coordinate defined in eq. (38)
z	Coordinate parallel to slot or void width
Z	Dimensionless coordinate defined in eq. (38)
X_v, Y_v	Location of air extractor in end void
δ	Dirac Delta Function
ξ	Dimensionless coordinate parallel to x
	Also, real part of complex variable defined in eq. (25)
η	Dimensionless coordinate parallel to y
	Also, imaginary part of complex variable defined in eq. (25)
ζ	Dimensionless coordinate parallel to z
ρ	Gas density
λ	Concentration layer vertical coordinate defined in eq. (66)
μ	Gas viscosity
ν	Gas kinematic viscosity
τ	Time unit (hours)
	Also, complex varible defined in eq. (33)

Θ	Dimensionless temperature
ω	Scale factor defined in eq. (6)
Γ	Gamma function
ψ	Stream function defined in eq. (64)

Subscripts

o	Reference value for T, p
1	Value at top of hold
n	Value associated with nth slot
v	Value associated with end void

Superscripts

*	Dimensionless, perturbation values, defined in eq. (38)
^	Dimensionless, perturbation value, defined in section 3
~	Dimensionless variables defined in eq. (20)

Operators

∇	Vector gradient
Δ	Laplacian

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Abstract

An analysis of the fluid flow and mass transfer induced by ventilation systems in containership holds was carried out. The result of the work was used to support the U.S. position before a committee of the International Convention on Safety to Life at Sea. The analysis consists of a detailed calculation of the forced motion through an interconnected set of narrow, stably stratified vertical air passages, which represent an idealized containership hold. The results of this calculation were then used to predict the vapor concentration of spilled volatile material assumed to lie at the bottom of the vertical air passages. The result is a set of formulae which determine the rate of extraction of volatile material as a function of hold geometry, ventilation parameters, and ambient stratification. The results are incorporated in a computer program which is described in detail. A variety of computed results are presented. The results indicate the crucial importance of locating the extractor as close to the hold bottom as technically possible.

1. INTRODUCTION

The purpose of this study was to obtain the information necessary to prepare a quantitative statement on the degree of fire hazard that might exist in the hold of a large containership as a function of the amount and nature of the hold ventilation and amount and kind of leakage of flammable liquid or gas cargo. The effort was mainly analytic although some scale model tests were conducted. Sea tests were conducted by Sealand Corporation to determine the degree to which the thermal conditions assumed by the analysis were found in practice.

Containerships play a major role in the U.S. Merchant Marine. The majority of the non-bulk sea-going cargo into and out of the U.S. is now moved in containers. Some of this cargo is classified as "dangerous cargo", such as flammable liquids and gases and are regulated in treaty provisions based on recommendations of the International Maritime Consultative Organization (IMCO).

Under existing regulations stowage limitations, resulting from the types and amounts of cargo classed as dangerous, reduce shipment scheduling flexibility. IMCO has considered new regulations which would somewhat relax the dangerous category definitions for ships with adequate hold ventilation or detection and inerting systems. The basis for their action is the belief, by some members of the committee, that ventilation would keep the concentration of leaking and vaporizing flammable gas below the flammable or explosive limit. However, prior to this study, there did not appear to be a rational basis for establishing a suitable rate of ventilation. A study on the scale of this one could not address the full range of situations which might arise but the most prevalent situation was considered. Using the results of this study a position was developed and presented by the U.S. representative to IMCO as a counter to the ad hoc opinions originally put forward by others. After discussion, a position close to the U.S. position was adopted by the committee.

Container freight forwarding is a highly automated process using ships often specifically built for container freight and complex dock side equipment matched to the ship design. Containers of a uniform size are closely stacked within the holds, filling all the space available after allowance for structure, container guides and spaces at the sides, especially near the ends of the ship, due to the non-rectangular shape of holds. Current practice loads a hold to its maximum capacity. In the center portion of a ship, with wing tanks occupying the space between the hull plating and the side combing of the hatch, the only significant voids would be between the top of the containers and the underside of the hatch covers; and at one end of the container stacks, where deep framing of the transverse bulkhead result in a array of rectangular spaces interconnected by lightening holes in the frames. The spaces between stacks of containers, between the containers and the wing tank walls, or between the end of the container stacks and the smooth (non-framed) side of a transverse bulkhead would be only that needed for the container guides, typically about 10 cm between stacks of containers and half this between the containers and bulkhead, see figure 1. On some ships there may be fixed, heavy longitudinal beams to support the hatch cover. The gaps between container stacks on either side of such a beam would be somewhat wider. Where wing tanks are not used and at the ends of the ship, a fairly large void will exist between the hull plating and the outermost container stack. This will be partially subdivided by the transverse and longitudinal framing. The container stacks rest on the flat, smooth double bottom tank top. Although an air space some 10 cm deep exists under the containers this is cut off from the inter-container gaps and end void by side and end rails or skirts of the container so that effective communication with this space is limited by the thickness of the corner pads of the containers, a gap perhaps less than 2 cm. Should a liquid be spilled on the tank top it would be able to flow under the containers as the ship rolled but liquid evaporated under the containers would not easily escape to the rest of the hold.

The accident scenario envisaged involves a container carrying general cargo including some flammable liquid in cans or drums. For any of a number of reasons -- a defective drum, inadequate dunnage and securing, rough handling of the container, etc. -- flammable liquid is assumed to escape into the interior of the container. Although a container in good condition is quite weather tight, an older container, especially if it has been roughly treated (a situation likely to accompany disruption of its cargo), may allow a liquid, spilled inside, to leak out. It is assumed that liquid does escape and flows down over the outside of the containers below to the bottom of the hold, where it accumulates in a puddle which is spread by rolling and pitching of the ship to wet the entire bottom of the compartment. In the case considered for the numerical examples used throughout this paper, the liquid is heptane and the tank top area is 324 m^2. If 208 liters (55 U.S. gallons) of liquid reached the bottom of the hold and spread uniformly over the tank top, the liquid layer would be only 2/3 mm thick.

Consider the implications of this accident first as it affects conditions inside the container and next as it affects conditions in the hold. Inside the container the air will be essentially stagnant for any plausible hold ventilation scheme. Accumulated liquid will evaporate reaching a local equilibrium concentration depending on the container temperature. Hold temperatures measured by Sealand on a run from Houston to Rotterdam [1][1] in

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[1] Numbers in brackets refer to references listed at the end of this report.

the fall of 1978 ranged from 10 to 28°C (50 to 83°F). From figure 2 [2] it is seen that the equilibrium vapor pressure of heptane, for these temperatures, ranges from 20 to 53 mm-Hg yielding corresponding volume concentrations of 2.6 to 7.0%. Lewis and Von Elbe [3] give the flammability limits for heptane in air as 1.2 and 6.7%. Thus the undiluted heptane vapors will lie within the flammable limits throughout the expected temperature range. Heptane (C_7H_{16}) vapors are heavier than air. The mean molecular weight at standard temperature and pressures of the equilibrium heptane-air mixture for this range of vapor pressures is 30.84 to 34.11 compared to 28.97 for air. This will tend to inhibit mixing of the heavy vapors with the rest of this air in the container but, over a long period of time, through diffusion, a substantial volume of combustible vapor could accumulate inside the container (121 to 312 gm of heptane/m^3 of air in a container with total volume about 90 m^3 and void volume estimated at 10 m^3). Our accident scenario supposed that the container would allow the spilled liquid to leak out but, of course, it might not, or might leak very slowly. Thus, if an ignition source of sufficient strength to ignite the vapors were found within the container, a vapor deflagration could occur followed by fire. Recall that this situation is independent of the amount and type of hold ventilation and that, for the chemical and temperatures chosen, there is little possibility of escaping danger by exceeding the rich flammable limit after a long time.

If the container leaks, some or most of the liquid can escape, possibly alleviating the hazard just described but creating another in the ship's hold. As already noted the liquid will form a thin but extensive puddle on the tank top. If there is a low point sump in the hold, a substantial amount of the spill may drain into it and could be pumped to a safe holding tank.

Such an arrangement seems the most suitable way to remove any substantial amount of liquid. However, evaporation will occur in the hold just as it does in the container, but, in the hold, ventilation can greatly reduce the hazard.

Consider first the zero ventilation situation in an unstratified hold. While, as just discussed, there might be 1 to 3 kilograms of fuel vapor in the container where the spill originated, the ship's hold is so large that, for a plausible spill volume, evaporation followed by thorough mixing might exhaust the available vapor before the lean limit concentrations were reached. For a hypothetical ship with wing tanks, i.e., minimal side voids, loaded with 10 rows of 35 foot containers across the hold each row 7 containers high, the total hold volume might be about 6,500 m^3 (230,000 ft^3) and the void volume 1,760 m^3 (62,000 ft^3). This void volume could carry, for the range of temperatures expected, from 210 to 550 kg heptane, or approximately the contents of 1-1/3 to 3-1/2 55 gallon drums. A very large ship without wing tanks would have considerably more void volume in its midships holds while, in the ends a ship, there could be considerably less void volume. In any event, the advantage of a low point sump becomes clearer in this context since it could remove much of the spill liquid before it evaporated. As noted earlier, the film of liquid from a 55 gallon spill, spread evenly over the tank top of a large ship is quite thin. Since some residual film, puddles in irregular low spots, etc., must be anticipated, there would be a significant reservoir for evaporation even with an efficient sump. This residual volume is difficult to estimate but, for a low viscosity liquid might be about 20 to 30 gallons in so large a space. For the void volume of our example (1760 m^3) at the lean limit concentration there would be 94 kilograms of heptane vapor or the result of evaporating 33 gallons. Thus, by using a sump, there is the possibility of keeping the average composition of the vapor below the flammable limit.

Although the average composition of the vapor might be kept below the flammable limits, during the evaporation process (while liquid remains) there will be a region near the liquid surface in which the vapor concentration will approach the equilibrium vapor concentration corresponding to the liquid temperature. As we have seen, this can be expected to be well within the flammable limits. The purpose of ventilation is to keep the volume of gas which is within the flammable limits as small as possible. If the air in the hold were continually stirred, for example, by natural convection created by an unstable vertical temperature gradient -- bottom of the hold warmer than the top, the same situation described under zero ventilation would apply. However, an unstable temperature gradient was observed only intermittently on the instrumented containership run from Houston to Rotterdam and then only in the upper portion of the hold. The lowest thermocouple was always the coolest. Throughout most of the voyage the hold air was stably stratified for all heights measured. In addition to the temperature stratification, if there are pools of flammable liquid at the bottom of the hold, the vapor just above these pools will be heavier than pure air. This may be expressed as an added equivalent thermal stratification by giving the temperature difference required to produce the same density difference in pure air as is produced by the fuel vapor. For heptane at the temperature observed, this ranges from about 20 to 50°C. By contrast the true thermal stratification on the instrumented sea run never exceeded 3°C, and was more typically less than 1°C. Thus the combination of a stable temperature field and heavy evaporated liquid vapor tends to be extremely stable near the tank top (hold bottom) and generally stable, though much less so, elsewhere.

If there were a transverse temperature difference, one side of the hold warmer than the other, a circulation would develop [4,5]. In an empty hold a narrow boundary layer flow would move up the warmer side across the top of the hold and down the cooler side. Near-stagnant conditions would be found in the interior of the hold. The flow across the tank top would also be confined to a thin boundary layer. In a loaded ship, due to the presence of the container stacks, this flow would be strongly inhibited except in the end void associated with the bulkhead framing and here the framing would considerably reduce the general flow. In practice, the flow induced by a transverse temperature gradient in the presence of a stable vertical gradient, would probably only be significant in the two side voids of a ship without wing tanks. The circulation would be between the sides of the ship and the outer side of the outermost container stacks. Such flow has not been considered in this study.

The flow that seems most likely to affect the vapor bubble over evaporating liquid on the tank top is that associated with forced ventilation. Obviously, for the well mixed case (unstable stratification) the location of the suction and inlet for the forced flow are relatively unimportant although they should be well separated. In the stably stratified case this is not true. Both since the stable case is more prevalent and since, in the unstable case, the suction may be located anywhere and might as well be placed advantageously for the stable situation, the stable case has been given priority in our study. With stable stratification and flammable vapors heavier than air originating from a liquid spill, the suction should be close to the bottom of the hold and the inlet placed well above it. As will be discussed in detail in the following sections, the air flow will at first spread laterally from the inlet with very limited vertical movement. There will be a relatively slow drift downward to the level of the suction followed by lateral movement in the plane of the suction, again with little vertical motion, to the suction location. If the suction is located above the tank top (at the bottom of the hold shown in figure 1) the gas below the suction will tend to be stagnant. In the stably stratified case, vertical movement of the gas is facilitated where it can exchange heat with its surroundings. The result is that the vertical drift from the level of the inlet to that of the suction is not uniform but concentrated in thin boundary layers adjacent to the container stacks and ship structure. The more stable the stratification the narrower these boundary layers become. For the geometry and temperature differences found in a typical container ship these boundary layers are only a few centimeters thick. The result is that virtually the same flow can move down the 10 cm wide gap between container stacks as down the several meter wide gap between the outermost container stack and the side of the ship. Only when the gap is narrower than the combined thickness of the two boundary layers is the flow decreased. This may occur in the gap between the end of the container stacks and the smooth side of the bulkhead.

In all the above, the accident was assumed to involve a liquid spill. Although this appears to be the most likely type of accident, some materials could be released whose vapors are lighter than air. To deal with this eventuality, it has been proposed that the forced ventilation inlet be located near but not at the top of the hold and that a suction pulling a minor fraction of the ventilation be provided at the highest point in the hold, just under the hatch cover.

2. BASIC ASSUMPTIONS OF THE THEORETICAL MODEL

In order to develop a quantitative model, it is necessary to know the geometry and thermal stratification of a typical container ship hold. The most obvious feature of such holds (on efficiently designed ships) is that most of the available space is occupied by containers. The only air spaces are narrow vertical slots between stacks of containers, similar but less narrow voids at ends and/or sides of the stacks, and a gap between the top of the container stacks and the hatches. The size and shape of these vary from ship to ship, and from one hold to the next on a given ship. The temperature distribution in each hold is dependent on both the ship and its thermal environment over a period of time. In general, the environment is highly dependent on the ships route and both seasonal and daily weather patterns. The conditions prevailing in tanks adjacent to the hold are also important and may vary markedly during a voyage. Given this environment, the complete determination of the thermal balance on a ship is itself a formidable task.

Rather than attempt to model the detailed features of a single hold and thermal environment, a set of simplifying assumptions is introduced, which permits the analysis to be reduced to a tractable size and scope, and still retain some dependence on the physical and geometric parameters described above. These assumptions are:

(1) The hold is rectangular. The air spaces consist of narrow rectangular vertical slots separating container stacks and a narrow rectangular vertical void at one end of the hold. The idealized hold is shown schematically in figure 3.

(2) The temperature distribution in the hold is stably stratified and varies linearly from top to bottom. The containers and ship hull are in thermal equilibrium with this distribution. Thus, all motions are due to ventilation.

(3) The ventilation system is designed so that air enters at the top of the hold and exits in the end void. The overall air volume flow is consistent with creeping motion (inertia forces unimportant).

Finally, in order to estimate the rate at which spilled material is picked up it is necessary to impose a spill scenario on the model. It is assumed that the spill material collects at the bottom of the slots between container stacks. The material is picked up as vapor in a concentration boundary layer formed at the bottom of the slot. All material caught up in this boundary layer is assumed to exit with the ventilation air. The analysis then proceeds as follows:

First, the conditions for low Reynolds number flow are established and the small scale motion in a single slot is determined. This leads to an equation for the pressure that governs the large scale motion in a single slot. This equation is then solved assuming that the pressure in the end void where the flow exits is known. The next step is the solution for the pressure in the end void, which ties together the large scale motion in the entire hold. Then the local flow in the bottom of each slot is obtained. The final step is the calculation of the concentration boundary layer in the slot bottom, which determines the actual pickup of spill material.

3. SLOT FLOW IN A STABLY STRATIFIED ENVIRONMENT

As mentioned above, the volume available for air movement in a containership hold may be usefully idealized as a collection of narrow vertical and horizontal slots. The analysis of the motion in a single slot is thus a necessary precondition for a study of the air movement throughout the hold. In order to proceed, we must first establish that the creeping flow regime is encountered for realistic values of the governing flow parameters. Then, approximate solutions to the equations of motion valid in the appropriate flow regime can be constructed. Finally, these solutions will be related to the large scale motion in the hold.

Consider a vertically oriented slot of width 2d, height h and length ℓ (figure 4). The equations governing the steady motion of a viscous incompressible fluid affected by buoyancy forces can be written in the Boussinesq approximation as:

$$\nabla \cdot \vec{u} = o$$

$$(\vec{u} \cdot \nabla)\,\vec{u} + \frac{1}{\rho}\nabla p^{*} + \left(\frac{T - T_o}{T_o}\right)\vec{g} = \nu\Delta\vec{u} \qquad (1)$$

$$(\vec{u} \cdot \nabla)\,T = (\nu/Pr)\Delta T$$

Here $\vec{u}$ is the velocity vector, p^{*} the pressure, and T the temperature in the fluid. The density ρ, kinematic viscosity ν and Prandtl number Pr are properties of the fluid taken as constant corresponding to the hold bottom temperature T_o. The gravitational acceleration $\vec{g}$ is directed vertically downward, while ∇ and Δ are respectively the gradient and Laplacian operators.

Equation (1) represents the conservation of mass, momentum, and energy respectively. It is anticipated that the ventilation system will be designed to induce mean (mass averaged) velocities in the slot whose order of magnitude is such that air actually in the hold bottom can be swept out several times per hour. Let m be the number of times per hour that a slot is swept out horizontally. Then a typical horizontal velocity must be of order $m\ell/\tau$, where τ is the period (one hour). The inertial terms (the non-linear terms) in the horizontal momentum balance are then of order $(m\ell/\tau)^2/\ell$; while the viscous terms are of order $\nu(m\ell/\tau)/d^2$. The ratio of these two terms indicates the relative importance of viscous and inertial effects. It will be called the "effective Reynolds number" in this report to distinguish it from more conventionally defined Reynolds numbers. This effective Reynolds number (Re) for horizontal motion in the slot, which determines the flow regime of interest, is given by

$$Re = \frac{md^2}{\nu\tau} .$$

For slot widths and sweep rates of interest the effective Reynolds number Re is typically in the range $1 \leq Re \leq 10$.

For this range of values, the horizontal flow is effectively one in which the pressure forces balance the viscous forces on the fluid, as in pipe flow and in bearing lubrication [6,7]. This occurs because the slot is so narrow in comparison to its length ($d/\ell \ll 1$) that velocities perpendicular to the plane of the slot (i.e. - in the z-direciton, see figure 4) are negligibly small compared with those in the plane of the slot. Although the above argument strictly applies to horizontal motions, it will be shown in detail below that the effect of stable stratification will be to reduce even further the importance of inertial effects on the fluid motion.

We now turn to a detailed study of the motion in the slot. Let P_o and T_o be reference values of the pressure and temperature of the air in the slot. The fluid velocity $\vec{u}$ may be expressed in component form (see figure 4) as:

$$\vec{u} = u\vec{i} + v\vec{j} + w\vec{k}.$$

The dependent variables describing the state of motion may be represented as follows:

$$p^* = p_o - \rho g y + \rho \left(\frac{T_1 - T_o}{T_o}\right) \frac{gh}{2} \left(\frac{y}{h}\right)^2 + p(x/\ell, y/h)$$

$$T = T_o + (T_1 - T_o)\, y/h + \theta(x/\ell, y/h, z/d)$$

$$u = u(x/\ell, y/h, z/d) \qquad (2)$$

$$v = v(x/\ell, y/h, z/d)$$

$$w = w(x/\ell, y/h, z/d)$$

Here, g is the magnitude of the gravitational acceleration and p is the dynamical part of the pressure. The remaining terms in the expression for p^* are the hydrostatic values of the pressure. The term linear in (y/h) in the expression for the temperature is the ambient stratification of the hold. This stratification is assumed to vary linearly between the upper temperature T_1 and T_0, where $T_1 > T_0$. The velocity component normal to the plane of the slot, w, is smaller than the in-plane components u and v by a factor d/ℓ or d/h. The conservation of momentum in the z direction immediately leads to the conclusion that the dynamic pressure p must be nearly independent of z.

It is convenient to work with non-dimensional variables defined as follows:

$$
\begin{aligned}
p &= (Re)\rho g h \left(\frac{T_1 - T_o}{T_o}\right) \hat{p}(\xi, \eta) \\
v &= (Re) g d \left(\frac{T_1 - T_0}{T_0}\right) \hat{v}(\xi, \eta, \zeta) \\
\theta &= (Re)(T_1 - T_o)\hat{\theta}(\xi, \eta, \zeta) \\
\xi &= x/\ell, \ \eta = y/h, \ \zeta = z/d
\end{aligned}
\tag{3}
$$

Substitution of the non-dimensional variables defined in equation (3) into the vertical momentum and energy conservation equations and neglecting terms of order $(d/h)^2$, $(d/\ell)^2$, or Re yields:

$$\frac{\partial \hat{p}}{\partial \eta} - \hat{\theta} = (G)^{-1/2} \frac{\partial^2 \hat{v}}{\partial \zeta^2}$$

$$\hat{v} = \frac{(G)^{-1/2}}{Pr} (h/d) \frac{\partial^2 \theta}{\partial \zeta^2} \qquad (4)$$

$$G = \left(\frac{T_1 - T_0}{T_0}\right) \frac{gd^3}{\nu^2}$$

The dimensionless parameter G, the Grashof number, is the fundamental parameter controlling the nature of the vertical motion in the slot. Its influence will be discussed in detail below.

Since $p(\xi,\eta)$ is independent of ζ, equation (4) can be solved for the dimensionless vertical velocity v and temperature perturbation $\hat{\theta}$ as functions of the vertical pressure gradient $\frac{\partial p}{\partial \eta}$. The boundary conditions associated with equation (4) are:

$$\hat{v}(-1) = \hat{v}(1) = 0$$

$$\hat{\theta}(-1) = \hat{\theta}(1) = 0 \qquad (5)$$

The physical meaning of equation (5) is that the vertical velocity and temperature perturbation must vanish at the sides of the slot. The first boundary condition follows from the no-slip condition. The second comes from the assumption that the ambient stratification in the slot is controlled by the temperature distribution in the containers, which varies linearly with height.

The solution to equations (4) and (5) is given by:

$$\hat{v} = \frac{\partial \hat{p}}{\partial \eta} (h/dPr)^{1/2} \{a(\omega) \cos(\omega\zeta) \cosh(\omega\zeta) - b(\omega) \sin(\omega\zeta) \sinh(\omega\zeta)\}$$

$$\hat{\theta} = \frac{\partial \hat{p}}{\partial \eta} \{1 + a(\omega) \sin(\omega\zeta) \sinh(\omega\zeta) + b(\omega) \cos(\omega\zeta) \cosh(\omega\zeta)\}$$

$$a(\omega) = - \frac{\sin(\omega) \sinh(\omega)}{-\sin^2(\omega) + \cosh^2(\omega)} \qquad (6)$$

$$b(\omega) = - \frac{\cosh(\omega) \cos(\omega)}{-\sin^2(\omega) + \cosh^2(\omega)}$$

$$\omega = \frac{1}{\sqrt{2}} (GPrd/h)^{1/4}$$

It should be noted that the above solution, while approximate in terms of the overall problem of interest, is in fact an exact solution of the equations of hydrodynamics for an infinitely long slot. This buoyancy layer was first found by Prandtl [8], and by Gill [9], and used by Gill [9], in his analysis of thermally driven slot convection. Gill's analysis has been experimentally verified by Elder [10]. In the present application, the solution corresponds to a forced stratified channel flow. In the limit of zero stratification:

$$\hat{v} = - \frac{\partial \hat{p}}{\partial \eta} (h/dPR)^{1/2} \omega^2(1-\zeta^2). \qquad (7)$$

Returning to dimensional variables, equation (7) can be rewritten in the classical form:

$$v = - \frac{1}{2} \frac{d^2}{\mu} \frac{\partial p}{\partial y} [1-(z/d)^2]; \quad u = - \frac{1}{2} \frac{d^2}{\mu} \frac{\partial p}{\partial x} [1-(z/d)^2] \qquad (8)$$

Here, μ is the viscosity of the air, and the solution for u has been added. For large stratification, ω is not small. As an example, for a stable stratification $T_1 - T_o$ of 3^oC, with the reference temperature $T_o = 300^oK$ and a slot half width of 10 cm and width to height ratio $d/h = .01$, $\omega = 5.3$. For values of $\omega > 3$, equation (6) simplifies to the form:

$$\hat{v} = -\frac{\partial \hat{p}}{\partial \eta}(h/dPr)^{1/2}\{e^{-\omega(1-\zeta)}\sin[\omega(1-\zeta)] + e^{-\omega(1+\zeta)}\sin[\omega(1+\zeta)]\} \quad (9)$$

Equation (9) represents a vertical flow that has effectively ceased except for a boundary layer of thickness $(\omega)^{-1}$ near each wall of the slot. Thus, for a given pressure gradient, there is much less vertical flow in the presence of stratification than in its absence. This can be seen more dramatically by calculating the vertical volume flux of air per unit of length. The vertical flux in dimensional variables is given by:

$$\int_{-d}^{d} v dz = \frac{2d^3}{3\mu}\frac{\partial p}{\partial y} f(\omega)$$

$$f(\omega) = \frac{3}{8\omega^3} \frac{\sinh(2\omega) - \sin(2\omega)}{-\sin^2(\omega) + \cosh^2(\omega)} \quad (10)$$

This should be compared with the horizontal volume flow per unit of height, which is:

$$\int_{-d}^{d} u dz = \frac{-2}{3}\frac{d^3}{\mu}\frac{\partial p}{\partial x} \quad (11)$$

Clearly, the function $f(\omega)$ is a measure of the effectiveness of the pressure gradient in producing a vertical flow. The function is presented in table 1. The decrease in effectiveness with increasing stratification (increasing ω) is quite obvious.

The final stage of this part of the calculation is the determination of the pressure in the slot. The pressure distribution is governed by the requirement that mass be conserved in the slot. Let the quantity $Q''(x,y)\,dA$ be the rate at which fluid is introduced by some external agent into the slot, where dA is the element of surface across which the fluid crosses. This may be an inlet or exit from a ventilation system or vent, or a cutout in an end wall. Using equations (10) and (11), the conservation of mass yields the following equation for the pressure:

$$\frac{\partial^2 p}{\partial x^2} + f(\omega)\,\frac{\partial^2 p}{\partial y^2} = -\frac{3}{2}\,\frac{\mu}{d^3}\,Q''(x,y) \qquad (12)$$

There are three situations covered by equation (12) which are of interest. First, if there is no opening into or out of the slot, then $Q'' = 0$. Second, if the flux through the opening is specified, then Q'' is a prescribed function. One such case of practical interest is a small opening at $x = x_o$, $y = y_o$ which a total flow rate Q_o is specified, the dimensions being small compared with the length or height of the slot. Then, Q'' is given by:

$$Q''(x,y) = Q_o\ \delta(x-x_o)\ \delta(y-y_o) \qquad (13)$$

Here, δ denotes the Dirac delta function. Finally, if the opening is large and the pressure is specified at the opening, then it is more convenient to consider the boundary of the opening as a boundary of the slot along which the pressure is specified. Then $Q'' = 0$ as before over the interior of the region of interest. However, the solution now must be obtained over the rectangular slot, with the correct pressure being specified at the open edge. The second and third cases are complementary in that the flow is specified and the pressure is calculated in the second instance; while the pressure is specified and the flow is calculated in the third.

4. THE SLOT PRESSURE DISTRIBUTION

The starting point for the analysis is equation (12), with Q" = 0. The boundary condition at the closed end of each slot is (see equation (11) and figure 4):

$$\frac{\partial p}{\partial x}(\ell/2, y) = 0 \tag{14}$$

At the open end, the pressure must be compatible with the end void pressure at that height. If the end void pressure at the n^{th} slot is denoted by $p_v(n,y)$; then the boundary condition at the open end is:

$$p(-\ell/2, y) = p_v(n, y) \tag{15}$$

At the bottom, since there is no flow through the floor of the hold, the boundary condition is (see equation (10)):

$$\frac{\partial p}{\partial y}(x, 0) = 0 \tag{16}$$

Rather than consider the geometry of the air gap at the top of the hold and its interaction with the upper boundary of the slot, it is more convenient to note that most cases of practical interest correspond to values of ω (see equation (6)) such that $f(\omega) << 1$. If ℓ/h is of order unity, then equations

(12) and (14) imply that, away from the top or bottom of the slot, p depends only on y. Let Q_n be the total flow of air drawn through the n^{th} slot. Then equation (10) and (12) imply that the pressure distribution over most of each slot is given by:

$$p = \frac{3}{2} \mu Q_n y / d_n^3 \ell_n f(\omega_n) \tag{17}$$

Now the same relation must hold in most of the end void, away from the top or bottom. This means that the total flow, Q, drawn through the hold by the ventilation system can be related to p by the formulae:

$$Q \equiv \sum_{n=o}^{N} Q_n = \frac{2}{3} \frac{p}{y} \sum_{n=0}^{N} d_n^3 \ell_n f(\omega_n) \tag{18}$$

The sum in equation (18) is assumed to extend over all slots and the end void. Eliminating the pressure from this expression yields the result:

$$Q_n = Q \ell_n d_n^3 f(\omega_n) / \sum_{n=o}^{N} d_n^3 \ell_n f(\omega_n) \tag{19}$$

Equation (19) is extremely important in what follows. It permits the flow in each slot to be related to the total flow drawn through the hold, Q. Thus, since Q is a prescribed system parameter, Q_n can be determined in advance as a function of the hold geometry and stratification. Physically, equations (17)-(19) mean that the stratification completely suppresses horizontal motion everywhere except near the top and bottom of each slot and the end void. Equation (12) then implies that the horizontal motion is only important in layers of order $\ell_n \sqrt{f(\omega_n)}$ in height near the top and bottom. The details of the motion near the top are of no interest. The only thing that matters is that the ventilation air enters there. The bottom horizontal motion must be calculated because it determines the pickup of evaporated spill material. However, it can now be calculated as if the slot were semi-infinite in height with the boundary condition as $y \to \infty$ given by equation (17).

To carry out the calculation, it is appropriate to proceed more formally. Let the pressure in the n^{th} slot be made non-dimensional as follows:

$$p = \frac{3}{2} \frac{\mu}{d_n^3} \frac{Q_n}{\sqrt{f(\omega_n)}} \tilde{p}(\tilde{x},\tilde{y})$$

$$\tilde{x} = x/\ell_n ; \; \tilde{y} = y/\ell_n \sqrt{f(\omega_n)} \qquad (20)$$

Then the boundary value problem can be stated in the form:

$$\frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2} + \frac{\partial^2 \tilde{p}}{\partial \tilde{y}^2} = 0$$

$$\frac{\partial \tilde{p}}{\partial \tilde{x}} (1/2, \tilde{y}) = 0$$

$$\frac{\partial \tilde{p}}{\partial \tilde{y}} (\tilde{x}, o) = 0 \qquad (21)$$

$$\lim_{\tilde{y} \to \infty} \tilde{p}(\tilde{x},\tilde{y}) = \tilde{y}$$

$$\tilde{p}(-1/2, \tilde{y}) = \tilde{p}_v(n, \tilde{y})$$

Since the dimensionless end void pressure $\tilde{p}_v(n,\tilde{y})$ is unknown at this point; it is desirable to seek the solution in a form which displays the dependence on $\tilde{p}_v(n,\tilde{y})$ explicity. This can be done with the aid of a Greens function $G(\tilde{x}, x_o, \tilde{y}, y_o)$, defined as the solution of the problem:

$$\frac{\partial^2 G}{\partial \tilde{x}^2} + \frac{\partial^2 G}{\partial \tilde{y}^2} = \delta(\tilde{x}-x_o)\ \delta(\tilde{y}-y_o)$$

$$\frac{\partial G}{\partial \tilde{x}}(1/2,\ \tilde{y}) = \frac{\partial G}{\partial \tilde{y}}(\tilde{x},\ o) = 0 \tag{22}$$

$$G(-1/2,\ \tilde{y}) = \lim_{\tilde{y}\to\infty} G(\tilde{x},\tilde{y}) = 0$$

The quantity δ in equation (22) denotes the Dirac delta function. Introduce p and G as defined by equations (21) and (22) into the divergence theorem in the form:

$$\oint (\tilde{p}\ \Delta G - G\ \Delta\tilde{p})\ dx_o dy_o = \oint (\tilde{p}\ \frac{\partial G}{\partial n_o} - G\ \frac{\partial \tilde{p}}{\partial n_o})\ dS_o \tag{23}$$

Here n_o denotes the outward pointing normal to the closed contour composed of the slot boundaries and a fixed large value of y_o. Now letting $y_o \to \infty$ and using equations (21) and (22), a formal solution is obtained for the slot pressure $\tilde{p}(\tilde{x},\tilde{y})$ as:

$$\tilde{p}(\tilde{x},\tilde{y}) = -\int_o^\infty \tilde{p}_v(n,y)\ \frac{\partial G}{\partial x_o}(-1/2,\ y_o;\ \tilde{x},\tilde{y})\ dy_o \tag{24}$$

In order to make equation (24) useful, it is necessary to determine G and $\tilde{p}_v$. The solution for G is independent of $\tilde{p}_v$, and only involves the slot geometry. The solution for $\tilde{p}_v$ will be obtained in the next section. The

Greens function $G(\tilde{x}, \tilde{y}, x_o, y_o)$ can now be obtained with the aid of a sequence of conformal mappings. The steps in the sequence are (see figure 5 for sketches of the mappings):

i) $\tau = \sin(\pi\zeta)$
$\zeta = \tilde{x} + i\tilde{y}$

This transforms the slot into a half space with the open end of the bottom at $\tau = -1$ (figure 5b).

ii) $\tau_1 = \tau + 1$

This moves the open end of the bottom to the origin (figure 5c).

iii) $W = \xi + i\eta = (\tau_1)^{1/2}$

This converts the slot into a quarter plane with the open end on the positive imaginary axis (figure 5d). Thus:

$$W = \xi + i\eta = 1 + \sin(\pi\zeta)^{1/2}$$

$$\xi = \{(a + \sqrt{a^2 + b^2})/2\}^{1/2}$$

$$\eta = \{(\sqrt{a^2 + b^2} - a)/2\}^{1/2} \qquad (25)$$

$$a = 1 + \sin(\pi\tilde{x}) \cosh(\pi\tilde{y})$$

$$b = \cos(\pi\tilde{x}) \sinh(\pi\tilde{y})$$

The Greens function can be written down immediately in the W plane. A solution is required with a logarithmic singularity at a point $\tilde{x} = x_o$, $\tilde{y} = y_o$ which vanishes for $\xi = 0$ and whose normal derivative vanishes for $\eta = 0$. The solution must be odd in ξ and even in η. The result is readily obtained in complex form as:

$$G + iJ = \frac{1}{2\pi} \{\log(W-W_o) + \log(W-\bar{W}_o) - \log(W+\bar{W}_o) - \log(W+W_o)\}$$

$$W_o \equiv W(x_o, y_o) = \xi(x_o, y_o) + i\eta(x_o, y_o) \tag{26}$$

$$\bar{W}_o \equiv \xi(x_o, y_o) - i\eta(x_o, y_o)$$

Equations (24) and (26) constitute the solution for the pressure in the slot once the end void pressure is known. For later use, it is necessary to compute the pressure gradient along the bottom of the slot. This calculation requires considerable care, due to the nearly singular nature of the integral. The result, after considerable algebra, is:

$$\frac{\partial\tilde{p}}{\partial\tilde{x}}(x,o) = \frac{\cos(\pi\tilde{x})}{\sqrt{1 + \sin(\pi\tilde{x})}} K(\tilde{x})$$

(27)

$$K(\tilde{x}) = \int_o^\infty \frac{d\tilde{p}_v}{dy_o}(y_o) \frac{\{\cosh(\pi y_o) - 1\}^{1/2} dy_o}{\sin(\pi\tilde{x}) + \cosh(\pi y_o)}$$

5. THE END VOID PRESSURE

The final stage in the determination of the large scale motion is the calculation of the end void pressure distribution. In order to proceed, it is necessary to assume that the end void can be treated in the same manner as the slots between container stacks, even though in many applications the relevant void width d_v and length ℓ_v are such that the ratios d_v/ℓ_v and d_v/h are not small. If these parameters are assumed to be small, then equation (12) applies, with x now measuring horizontal distance along the end void. The major difference between the slots and the end void lies in the appearance of non-trivial sources and sinks $Q''(x,y)$ in the end void.

The slots between container stacks are narrow compared with the length or height of the end void. Hence, the fluid issuing from them can be represented as line sources of fluid in the form:

$$Q''_{slot}(n) = Q_n \, \delta(x-x_n)q_n(y) \tag{28}$$

Here Q_n is the total flux issuing from the n^{th} slot, as given by equation (19), δ is again the Dirac delta function operating at the horizontal location of the n^{th} slot, and $q_n(y)$ determines the distribution of flow with respect to height. The distribution function $q_n(y)$ is normalized so that:

$$\int_0^\infty q_n(y)dy = 1$$

The air extraction system is assumed to have physical dimensions which are small compared with the dimensions of the end void. Hence, it can be represented as a delta function sink of strength Q, since it exhausts all the air drawn into the hold. The geometry is sketched in figure (6).

The pressure in the end void is then determined by the solution to the following system of equations:

$$\frac{\partial^2 p}{\partial x^2} + f(\omega_v) \frac{\partial^2 p}{\partial y^2} = \frac{-3}{2} \frac{\mu}{d_v^3} Q''(x,y)$$

$$Q''(x,y) = \sum_{n=1}^{N} Q_n \, \delta(x-x_n) \, q_n(y) - Q\delta(x-x_v)\delta(y-y_v)$$

$$\frac{\partial p}{\partial x} \left(\frac{\ell_v}{2}, y\right) = \frac{\partial p}{\partial x} \left(\frac{-\ell_v}{2}, y\right) = 0 \qquad (29)$$

$$\frac{\partial p}{\partial y} (x,o) = 0$$

$$\lim_{y \to \infty} p(x,y) = \frac{3}{2} \mu Q_o y/d_v^3 \ell_v f(\omega_v)$$

Here (x_v, y_v) is the location of the air extractor, and Q_o is the flow which originates in the end void, as determined by equation (19) with the void geometric parameters.

The solution procedure is similar to that employed in the previous section. The equations are made non-dimensional in the form:

$$p = \frac{3}{2} \frac{\mu}{d_v^3} \frac{Q_o}{\sqrt{f(\omega_v)}} \tilde{p}(\tilde{x},\tilde{y})$$

$$\tilde{x} = x/\ell_v ; \quad \tilde{y} = y/\ell_v \sqrt{f(\omega_v)}$$

$$\frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2} + \frac{\partial^2 \tilde{p}}{\partial \tilde{y}^2} = - \sum_{n=1}^{N} \frac{Q_n}{Q_o} \delta(\tilde{x}-\tilde{x}_n)\, q_n(\tilde{y}) + \left(1 + \sum_{n=1}^{N} \frac{Q_n}{Q_o}\right) \delta(\tilde{x}-\tilde{x}_v)\delta(\tilde{y}-\tilde{y}_v) \tag{30}$$

$$\frac{\partial p}{\partial \tilde{x}} (\pm \tfrac{1}{2}, \tilde{y}) = \frac{\partial p}{\partial \tilde{y}} (\tilde{x},o) = 0$$

$$\lim_{\tilde{y} \to \infty} \tilde{p}(\tilde{x},\tilde{y}) = \tilde{y}$$

A Greens function is again introduced, this time solving the following system of equations:

$$\frac{\partial^2 G}{\partial \tilde{x}^2} + \frac{\partial^2 G}{\partial \tilde{y}^2} = \delta(\tilde{x}-\tilde{x}_o)\, \delta(\tilde{y}-\tilde{y}_o)$$

$$\frac{\partial G}{\partial \tilde{x}} (\tilde{x} = \pm \tfrac{1}{2}, \tilde{y}, \tilde{x}_o, \tilde{y}_o) = 0 \tag{31}$$

$$\frac{\partial G}{\partial \tilde{y}} (\tilde{x}, 0, \tilde{x}_o, \tilde{y}_o) = 0$$

$$\lim_{\tilde{y} \to \infty} G\, (\tilde{x}, \tilde{y}, \tilde{x}_o, \tilde{y}_o) = y$$

Substitution of equations (30) and (31) into equation (23) then yields the result:

$$\tilde{p}(\tilde{x},\tilde{y}) = \left(1 + \sum_{n=1}^{N} \frac{Q_n}{Q_o}\right) G(\tilde{x}, \tilde{y}, \tilde{x}_v, \tilde{y}_v)$$

$$- \sum_{n=1}^{N} \frac{Q_n}{Q_o} \int_o^\infty q_n(\tilde{y}_o)\, G(\tilde{x}, \tilde{y}, \tilde{x}_n, \tilde{y}_o)\, d\tilde{y}_o \qquad (32)$$

The solution is completed by specifying G and q_n. The Green's function is determined by noting that the first of the transformations employed in the previous section maps the end void into a half plane. The solution for G is then readily obtained as:

$$G + iJ = \frac{1}{2\pi} \{\log(\tau-\tau_o) + \log(\tau-\bar{\tau}_o)\}$$

$$\tau = \sin(\pi\zeta) = \sin(\pi\tilde{x}) \cosh(\pi\tilde{y}) + i \cos(\pi\tilde{x}) \sinh(\pi\tilde{y})$$

$$\tau_o = \sin(\pi\tilde{x}_o) \cosh(\pi\tilde{y}_o) + i \cos(\pi\tilde{x}_o) \sinh(\pi\tilde{y}_o) \qquad (33)$$

$$\bar{\tau}_o = \sin(\pi\tilde{x}_o) \cosh(\pi\tilde{y}_o) - i \cos(\pi\tilde{x}_o) \sinh(\pi\tilde{y}_o)$$

The flow distribution functions, q_n, are in reality not arbitrary, but must be determined by the condition that the pressures as computed from equations (32) and (33) lead to the same flows when the solutions given by these equations are substituted into equation (24) and equation (24) is differentiated to obtain the flow out of each slot. In general, this leads to a system of N integral equations for the void pressure at each slot. The solution can be approximated with reasonable accuracy, (i.e enough accuracy to evaluate equation (27)) by noting several points. First, the fact that the total flow issuing from each slot is known implies the constraint given by equation (30) on $q_n(y)$. Second, the flow should be greatest at height

$\tilde{y} = \tilde{y}_v$, since that is the level at which the air is drawn out. Third, the flow should ultimately decay exponentially with distance away from its maximum, since the integral equations have the Greens functions for kernels, and the Greens functions all exhibit this type of decay. Finally, examination of equations (27) and (32) shows that the pressure cannot be sensitive to details of the shape of $q_n(\tilde{y})$. Hence, in the spirit of Carrier [11], the following form for $q_n(\tilde{y})$ is postulated:

$$q_n(\tilde{y}) = \frac{\pi}{[2-e^{-\pi\tilde{y}_v}]} \exp\{-\pi\left|\tilde{y}-\tilde{y}_v\right|\} \tag{34}$$

Equation (34) is consistent with all the points mentioned above. It also permits the integral in equation (32) to be evaluated in closed form. The result, after some extremely tedious algebra is:

$$\tilde{p}(\tilde{x},\tilde{y}) = \left(1 + \sum_{n=1}^{N} \frac{Q_n}{Q_o}\right) G(\tilde{x},\tilde{y};\, \tilde{x}_v,\tilde{y}_v)$$

$$+ \sum_{n=1}^{N} \frac{Q_n}{Q_o} \frac{1}{2\pi(2-e^{-\pi\tilde{y}_v})} \{ \sum_{j=1}^{4} L(t_j)$$

$$- \left(\frac{2-e^{-\pi\tilde{y}_v}}{2}\right) \log\,[(1-a_j)^2 + b_j^2]\}$$

$$L(t_j) = 1 + e^{\pi\tilde{y}_v} \left\{ \frac{a_j}{2} \log \left[\frac{e^{-\pi\tilde{y}_v} - a_j{}^2 + b_j^2}{a_j^2 + b_j^2}\right]\right.$$

$$\left. + \left|b_j\right| [\arctan\left(\frac{a_j - e^{-\pi\tilde{y}_v}}{\left|b_j\right|}\right) - \arctan\left(\frac{a_j}{\left|b_j\right|}\right)] \right\}$$

$$+ \log \left[\frac{(1-a_j)^2 + b_j^2}{(e^{-\pi \tilde{y}_v} - a_j)^2 + b_j^2} \right]$$

$$- \frac{1}{2} a_j \frac{e^{-\pi \tilde{y}_v}}{(a_j^2 + b_j^2)} \log \left[\frac{(1 - a_j)^2 + b_j^2}{(1 - a_j e^{\pi \tilde{y}_v})^2 + (b_j e^{\pi \tilde{y}_v})^2} \right] \tag{35}$$

$$- \frac{e^{-\pi \tilde{y}_v} |b_j|}{(a_j^2 + b_j^2)} \left\{ \arctan \left(\frac{a_j - e^{-\pi \tilde{y}_v}}{|b_j|} \right) - \arctan \left(\frac{a_j - 1}{|b_j|} \right) \right\}$$

$$a_1 = -e^{\pi \tilde{y}} \cos [\pi(\tilde{x} + \tilde{x}_n)]$$

$$b_1 = e^{\pi \tilde{y}} \sin [\pi(\tilde{x} + x_n)]$$

$$a_2 = e^{-\pi \tilde{y}} \cos [\pi(\tilde{x} - \tilde{x}_n)]$$

$$b_2 = e^{-\pi \tilde{y}} \sin [\pi(\tilde{x} - \tilde{x}_n)]$$

$$a_3 = -e^{-\pi \tilde{y}} \cos [\pi(\tilde{x} + \tilde{x}_n)]$$

$$b_3 = e^{-\pi \tilde{y}} \sin [\pi(\tilde{x} + \tilde{x}_n)]$$

$$a_4 = e^{\pi \tilde{y}} \cos [\pi(\tilde{x} - \tilde{x}_n)]$$

$$b_4 = e^{\pi \tilde{y}} \sin [\pi(\tilde{x} - \tilde{x}_n)]$$

6. THE BOTTOM MOTION

When the vertical distance above the hold bottom becomes comparable to the slot width, the flow pattern departs from that calculated in previous sections. While the length ℓ of the slot is still long compared with the half-width d, the vertical scale is now of order d since the downward flow must terminate at the bottom. The boundary layers at the sides of each slot, which carry the ventilation air downward, must spill out into the bottom across the full width of the slot. The horizontal motion must also adjust so that it can come to rest at the bottom.

To proceed, we consider the dimensional dependent variables introduced in equation (2). Substituting these into the linearized form of equation (1) (recall that $Re \sim O(1)$), the equations of motion become:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$\frac{\partial p}{\partial x} = \mu \Delta u$$

$$\frac{\partial p}{\partial y} - \frac{\rho g}{T_o} \Theta = \mu \Delta v \qquad (36)$$

$$\frac{\partial p}{\partial z} = \mu \Delta w$$

$$\frac{T_1 - T_o}{h} v = \frac{\mu}{\rho Pr} \Delta \Theta$$

The geometry is shown schematically in figure (7). Equation (36) is to be solved subject to the following boundary conditions:

$$\begin{aligned} &u(x, y, \pm d) = u(x, 0, z) = 0 \\ &v(x, y, \pm d) = v(x, 0, z) = 0 \\ &w(x, y, \pm d) = w(x, 0, z) = 0 \\ &\Theta(x, y, \pm d) = \Theta(x, 0, z) = 0 \end{aligned} \tag{37}$$

Finally, for $y >> d$, the solutions for u, v, w, and Θ must merge smoothly with those obtained in sections 2-5. This statement will be made in a more quantitative fashion below.

The solution procedure is based on explicitly recognizing the differences between the four relevant length scales in the problem. These scales are, in decreasing order of magnitude:

1.) The slot length ℓ
2.) The scale height for large scale motion ($\ell \sqrt{f(\omega)}$)
3.) The slot half width d
4.) The slot wall boundary layer thickness (d/ω)

The slot bottom region is now divided into two wall boundary layers and an interior region. In the interior region the dependent variables are expanded in an ascending series in the parameter (d/ℓ) of the form:

$$p = \frac{3}{2} \frac{\mu Q_o}{d^3\sqrt{f(\omega)}} \{\tilde{p}(\tilde{x},0) + (\frac{d}{\ell})^2 p^*(\tilde{x},Y,Z) + ...\}$$

$$u = \frac{3}{2} \frac{Q_o}{\ell d\sqrt{f(\omega)}} \{u^*(\tilde{x},Y,Z) + ...\}$$

$$v = \frac{3}{2} \frac{Q_o}{\ell d\sqrt{f(\omega)}} (\frac{d}{\ell}) \{v^*(\tilde{x},Y,Z) + ...\} \tag{38}$$

$$w = \frac{3}{2} \frac{Q_o}{\ell d\sqrt{f(\omega)}} (\frac{d}{\ell}) \{w^*(\tilde{x},Y,Z) + ...\}$$

$$\Theta = \frac{T_o}{\rho g d} \frac{3}{2} \frac{\mu Q_o}{d^3\sqrt{f(\omega)}} (\frac{d}{\ell})^2 \{\Theta^*(\tilde{x},Y,Z) + ...\}$$

$$\tilde{x} = x/\ell; \; Y = y/d; \; Z = z/d$$

Note that in equation (38); $\tilde{p}(\tilde{x},0)$ is the pressure obtained from the calculation of the large scale motion in section 4. The velocity components and temperature are scaled to ensure consistency with the large scale motion and with each other. Substitution of equation (38) into equation (36) and ignoring terms of order $(d/\ell)^2$ yields:

$$\frac{\partial u^*}{\partial \tilde{x}} + \frac{\partial v^*}{\partial Y} + \frac{\partial w^*}{\partial Z} = 0$$

$$\frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x},0) = \frac{\partial^2 u^*}{\partial Y^2} + \frac{\partial^2 u^*}{\partial Z^2} \tag{39}$$

$$\frac{\partial p^*}{\partial Y} - \Theta^* = \frac{\partial^2 u^*}{\partial Y^2} + \frac{\partial^2 w^*}{\partial Z^2}$$

Since the driving force in equation (39), $\frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x},0)$ is known, the velocity component in the direction of the slot, u*, can be obtained separately from the other variables, as the solution of (recall the second of equation (8)):

$$\frac{\partial^2 u^*}{\partial Y^2} + \frac{\partial^2 u^*}{\partial Z^2} = \frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x},0)$$

$$u^* (\tilde{x}, 0, Z) = u^* (\tilde{x}, Y, -1) = u^* (\tilde{x}, Y, +1) = 0 \qquad (40)$$

$$\lim_{y \to \infty} u^* (\tilde{x}, Y, Z) - \frac{1}{2} \frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x}, 0) (1-Z^2)$$

To proceed, u* is written as the sum of the large scale motion near the bottom plus a correction.

$$u^* = -\frac{1}{2} \frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x}, 0) (1-Z^2) + \bar{u}$$

$$\frac{\partial^2 \bar{u}}{\partial Y^2} + \frac{\partial^2 \bar{u}}{\partial Z^2} = 0$$

$$\bar{u} (\tilde{x}, Y, -1) = \bar{u} (\tilde{x}, Y, +1) = 0 \qquad (41)$$

$$\bar{u} (\tilde{x}, 0, Z) = \frac{1}{2} \frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x}, 0) (1-Z^2)$$

$$\lim_{Y \to \infty} \bar{u} = 0$$

The correction $\bar{u}$ can be expressed in terms of a Green's function $G(Y, Z; Y_o, Z_o)$ in a manner analogous to that described in previous sections. The result of the calculation is:

$$\bar{u}(\tilde{x}, Y, Z) = -\frac{1}{2}\frac{\partial\tilde{p}}{\partial\tilde{x}}(\tilde{x},0)\int_{-1}^{1} dZ_o(1-Z_o^2)\frac{\partial G}{\partial Y_o}(Y, Z; 0, Z_o)$$

$$G + iJ = \frac{1}{2\pi}\{\log(\phi-\phi_o) - \log(\phi-\bar{\phi}_o)\}$$

$$\phi = \sin(\pi\lambda);\ \lambda = Z + iY \tag{42}$$

$$\phi_o = \sin(\pi\lambda_o);\ \lambda_o = Z_o + iY_o$$

$$\bar{\phi}_o = \sin(\pi\bar{\lambda}_o);\ \bar{\lambda}_o = Z_o - iY_o$$

The final expression for u* can be rewritten in a more convenient form for computation by employing the Cauchy-Riemann equations to eliminate $\frac{\partial G}{\partial Y_o}$. The result is:

$$u^*(\tilde{x}, Y, Z) = -\frac{\partial\tilde{p}}{\partial\tilde{x}}(\tilde{x}, 0)\{\frac{1}{2}(1-Z^2) - \int_{-1}^{1} dZ_o Z_o\, J(Y, Z; 0, Z_o)\}$$

$$J = \frac{1}{\pi}\arctan\left\{\frac{I(Z,Y)}{R(Z,Y) - R(Z_o,0)}\right\}$$

$$\text{if } R(Z,Y) > R(Z_o,0); \tag{43}$$

$$J = \frac{1}{\pi}\left\{\pi - \arctan\left[\frac{I(Z,Y)}{R(Z_o,0) - R(Z,Y)}\right]\right\}$$

$$\text{if } R(Z_o,0) > R(Z,Y).$$

The quantities I and R are given by:

$$R(Z,Y) = \sin\left(\frac{\pi}{2} Z\right) \cosh\left(\frac{\pi}{2} Y\right)$$

$$I(Z,Y) = \cos\left(\frac{\pi}{2} Z\right) \sinh\left(\frac{\pi}{2} Y\right) \tag{44}$$

Note that u* as given by equations (43) and (44) has the form:

$$u^* = -\frac{\partial \tilde{p}}{\partial \tilde{x}} (\tilde{x}, 0)\, U(Y, Z) \tag{45}$$

Thus, the velocity profile at each axial station $\tilde{x}$ = constant has the same "universal profile" U(Y,Z). This profile is displayed in figure (8). The $\tilde{x}$ dependence can be factored out of all the variables in equation (39); the resulting decomposition being given by:

$$v^* = \frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2} (\tilde{x}, 0)\, V(Y, Z)$$

$$w^* = \frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2} (\tilde{x}, 0)\, W(Y, Z)$$

$$\Theta^* = \frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2} (\tilde{x}, 0)\, \Theta(Y, Z) \tag{46}$$

$$p^* = \frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2} (\tilde{x}, 0)\, P(Y, Z)$$

The profile functions V, W, Θ, and P satisfy:

$$\frac{\partial V}{\partial Y} + \frac{\partial W}{\partial Z} = U$$

$$\frac{\partial P}{\partial Z} = \frac{\partial^2 W}{\partial Y^2} + \frac{\partial^2 W}{\partial Z^2}$$

$$\frac{\partial P}{\partial Y} - \Theta = \frac{\partial^2 V}{\partial Y^2} + \frac{\partial^2 V}{\partial Z^2} \qquad (47)$$

$$(\omega^4)\ V = \frac{\partial^2 \Theta}{\partial Y^2} + \frac{\partial^2 \Theta}{\partial Z^2}$$

In order to proceed further, it is necessary to consider the dependence of the solutions on ω. In particular, the structure of the wall boundary layers (of thickness $(\omega)^{-1}$ on the slot half-width scale) must be determined (see figure 7). The boundary layer structure can be found from equation (47) without loss of generality; since the $\tilde{x}$ dependence factors out in the form given by equation (47) everywhere in the slot bottom. Symmetry considerations then permit attention to be confined to the wall layer near $Z = -1$, the layer near $Z = +1$ being identical. In this region:

$$V = \omega\ \hat{V}\ (\zeta,\ Y)$$

$$W = \hat{W}\ (\zeta,\ Y)$$

$$\Theta = \omega^3\ \hat{\Theta}\ (\zeta,\ Y) \qquad (48)$$

$$P = \omega^3\ \hat{P}\ (\zeta,\ Y)$$

$$\zeta = \omega\ (Z + 1)$$

Substitution of expressions (48) into equation (47) and keeping the leading order terms in ω leads to the wall boundary layer equations in the form:

$$\frac{\partial \hat{V}}{\partial Y} + \frac{\partial \hat{W}}{\partial \zeta} = 0$$

$$\frac{\partial \hat{P}}{\partial \zeta} = 0 \tag{49}$$

$$\frac{\partial \hat{P}}{\partial Y} - \hat{\Theta} = \frac{\partial^2 \hat{V}}{\partial \zeta^2}$$

$$\hat{V} = \frac{\partial^2 \hat{\Theta}}{\partial \zeta^2}$$

At the wall, $\zeta = 0$, the velocity components and the temperature perturbation must vanish (the latter due to the assumed equilibrium between container stacks and hold stratification). As $\zeta \to \infty$ these solutions must match the expressions for V, W, Θ, and P (which have not yet been found) in the interior of the slot bottom region. For the present, we assume only that all quantities are bounded in the interior, as $\zeta \to \infty$.

Equation (49) may be readily solved by noting that, from the second of these equations:

$$\hat{P} = \hat{P}(Y) \tag{50}$$

Although $\hat{P}(Y)$ is as yet unknown, $\hat{V}$ and $\hat{\Theta}$ may then be found in terms of $\hat{P}(Y)$ as:

$$\hat{\Theta} = \frac{\partial P}{\partial Y} \ \{1-\exp\ (-\zeta/\sqrt{2})\ \cos\ (\zeta/\sqrt{2})\}$$

$$\hat{V} = -\frac{\partial P}{\partial Y} \exp\ (-\zeta/\sqrt{2})\ \cos\ (\zeta/\sqrt{2}) \tag{51}$$

Note that as $\zeta \to \infty$ (i.e. as the interior of the bottom region Θ is approached)

$$\hat{\Theta} \to \frac{d\hat{P}}{dY}$$

$$\hat{W} \to (2)^{-1/2} \frac{d^2\hat{P}}{2Y^2} \tag{52}$$

$$\hat{V} \to 0$$

In order for the interior functions (the solutions to equation (47)) to have proper scaling with respect to ω, they must be consistent with equation (52) as $Z \to \pm 1$. This can be achieved by rescaling as follows:

$$V(Y,Z) = (\omega)^{-1} V_I(Y,Z)$$

$$\Theta(Y,Z) = (\omega)^3\ \Theta_I(Y,Z) \tag{53}$$

$$P(Y,Z) = (\omega)^2\ P_I(Y,Z)$$

The leading terms in the interior equations then become:

$$\frac{\partial W}{\partial Z} = U$$

$$\frac{\partial P_I}{\partial Z} = 0 \qquad (54)$$

$$\frac{\partial P_I}{\partial Y} - \Theta_I = 0$$

From the second of equation (54) and equation (50):

$$P_I = \hat{P}(Y) \qquad (55)$$

The last of equation (54) is now consistent with the first limit in equation (52), yielding the result:

$$\Theta_I = \frac{d\hat{P}}{dY}(Y) \qquad (56)$$

Finally, the first of equation (54) yields:

$$W = \int_o^Z U dZ$$

where

$$U = \frac{1}{2}(1-Z^2) - \int_{-1}^{1} dZ_o Z_o J(Y, Z; 0, Z_o) \qquad (57)$$

(see equation (43)).

The transverse profile W is displayed in figure 9. Note that U is symmetric in Z, so W is anti-symmetric. The remaining unknown $\hat{P}(Y)$ is determined by requiring that $W(\pm 1, Y)$ be cosistent with the matching condition given the second of equation (52). Thus:

$$\frac{d^2\hat{P}}{dY^2} = - \sqrt{2} \int_0^1 U(Z,Y)dZ \qquad (58)$$

This equation can be integrated once with respect to Y, using the value $\frac{d\hat{P}}{dY}(0) = 0$ to ensure that the vertical velocity in the wall layer vanishes at $Y = 0$ (see equation (51)).

The most important results of this section are equations (43) and (57), which yield the profiles for the two principal velocity components in the bottom region. These profiles will now be used in the calculation of the vapor pickup in this region.

7. THE VAPOR PICKUP

The calculation of the vapor pickup requires a solution for the vapor concentration gradient at the bottom of the hold. In order to proceed, it is necessary to recall the spill scenario postulated in section 2. It is now further assumed that the bulk of the pickup takes place along the bottom, but outside the wall boundary layers. The concentration $C(x,y,z)$ then obeys the equation:

$$u \frac{\partial C}{\partial X} + w \frac{\partial C}{\partial Z} = D \Delta C \qquad (59)$$

Here D is the diffusivity of the spill vapor in air, Δ is again the Laplacian operator; and u and w are the velocity components determined in the previous section. At y=0, the concentration is assumed to be C_o, the equilibrium vapor pressure at the temperature corresponding to the hold bottom. Outside the layer, there is no vapor; C=0.

We now non-dimensionalize the velocities and coordinates as in equation (38). The concentration equation (59) then takes the form:

$$u^* \frac{\partial C}{\partial \tilde{x}} (\tilde{x},Y,Z) + w^* \frac{\partial C}{\partial Z} (\tilde{x},Y,Z) = \frac{1}{R_e^* S_c} \Delta_2 C$$

$$\Delta_2 C \equiv \frac{\partial^2 C}{\partial Y^2} + \frac{\partial^2 C}{\partial Z^2} \qquad (60)$$

$$R_e^* = \frac{3Q_o}{2\ell d\sqrt{f(\omega)}} \left(\frac{d}{\nu}\right) \left(\frac{d}{\ell}\right)$$

$$S_c = \nu/D$$

Equation (60) must be solved subject to the boundary conditions:

$$C(\tilde{x},0,Z) = C_o \qquad (61)$$

$$\lim_{Y \to \infty} C(\tilde{x},Y,Z) = 0$$

The solution procedure employed is a generalization to three dimensions of that used by Lighthill [12] in obtaining his heat transfer formula. Recall that equations (45), (46) and (57) allow u* and w* to be expressed as:

$$u^* = - \frac{\partial \tilde{P}}{\partial \tilde{x}} (\tilde{x},0) \frac{\partial W}{\partial Z} (Y,Z)$$

$$w^* = \frac{\partial^2 \tilde{P}}{\partial \tilde{x}^2} (\tilde{x},0)\, W(Y,Z) \tag{62}$$

Following Lighthill, the vertical dependence of velocity profiles is approximated by a linear function.

$$W(Y,Z) \cong W_o(Z)Y, \quad W_o \equiv \left(\frac{\partial W}{\partial Y}\right)_{Y=0} \tag{63}$$

This approximation may be justified in several ways. First, when the Schmidt number $S_c >> 1$, it is rigorously true that this simplification yields the asymptotic solution for the concentration profile. Lighthill has shown that in the case of heat transfer, the approximation works quite well for Prandtl numbers of 0.7, corresponding to air. In the present application, S_c is usually in the range $1.5 < S_c < 2$. For this range of Schmidt numbers, the concentration field is largely controlled by the velocity profiles near the bottom. Inspection of figures (8) and (9) shows that the velocity profiles are fairly linear in this region. Finally, it should be noted that only the wall concentration gradient is required, not the whole concentration profile. Such information can be (and often is) obtained using much cruder profile information than will emerge from this calculation.

It is convenient to express the velocity components in terms of a stream function $\psi(\tilde{x},Z)$ defined as:

$$\psi(\tilde{x},Z) = - \frac{\partial \tilde{P}}{\partial \tilde{x}} (\tilde{x},o)\, W_o(Z) \tag{64}$$

The velocity components are given by:

$$u^* = Y \frac{\partial \psi}{\partial Z} ; \qquad w^* = - Y \frac{\partial \psi}{\partial \tilde{x}} \tag{65}$$

The vertical coordinate is now rescaled as follows:

$$\lambda = (R_e^* S_c)^{1/3} Y \tag{66}$$

The concentration equation now becomes:

$$\eta \left\{ \frac{\partial \psi}{\partial Z} \frac{\partial C}{\partial \tilde{x}} - \frac{\partial \psi}{\partial \tilde{x}} \frac{\partial C}{\partial Z} \right\} = \frac{\partial^2 C}{\partial \lambda^2} \tag{67}$$

The solution of equation (67) depends crucially on the observation that curves of constant ψ represent the trace of the streamlines calculated in section 6 on the bottom. These streamlines originate in the wall layer at the side of each container stack. Let s denote distance along each streamline with the origin at the point where the streamline emerges from the wall (see figure 10). Using s, ψ as independent variables in place of $\tilde{x}$, Z; equation (67) becomes:

$$q(s,\psi) \lambda \frac{\partial C}{\partial s} = \frac{\partial^2 C}{\partial \lambda^2} ; \qquad q^2 = \left(\frac{\partial \psi}{\partial Z}\right)^2 + \left(\frac{\partial \psi}{\partial \tilde{x}}\right)^2 \tag{68}$$

At s=0; the ventilation air has just entered the bottom region; hence C=0. At $\lambda=0$; $C=C_o$ and $C \to 0$ and as $\lambda \to \infty$ from equation (61). This is a relatively straightforward problem. To proceed, we introduce a modified streamwise variable ξ defined as:

$$\xi = \int_o^s ds/q(s,\psi) \tag{69}$$

then

$$\eta \frac{\partial C}{\partial \xi} = \frac{\partial^2 C}{\partial \lambda^2} \tag{70}$$

Introducing laplace transforms with respect to ξ; equation becomes:

$$p\lambda\bar{C} = \frac{\partial^2 \bar{C}}{\partial \lambda^2}$$

$$\bar{C} = \int_0^\infty e^{-p\xi} C(\xi,\lambda)d\xi \tag{71}$$

$$\bar{C}(\xi,0) = \frac{C_o}{p} \; ; \; \bar{C} \to 0 \text{ as } \eta \to \infty$$

The solution for $\bar{C}$ satisfying equation (71) is readily found [13] to be:

$$\bar{C} = \frac{C_o}{p} \Gamma\ (2/3)\ (3)^{2/3} Ai\ ((p)^{1/3}\lambda) \tag{72}$$

Here Ai is the Airy function, and Γ the Gamma function as defined in reference [13].

Although inversion of $\bar{C}$ to obtain the concentration profile would be a formidable undertaking, the problem becomes tractable if only the wall concentration gradients are required. The mass flux picked up at each point by the ventilation system, $\dot{m}$, is given by:

$$\dot{m} = - D \frac{\partial C}{\partial y}$$

$$= - \frac{D}{d} (R_e^* S_c)^{1/3} \frac{\partial C}{\partial \lambda} \qquad (73)$$

From equation (72), the laplace transform $\bar{\dot{m}}$ is readily computed as:

$$\bar{\dot{m}} = \frac{D}{P} (R_e^* S_c)^{1/3} C_o (3)^{1/3} \frac{\Gamma(2/3)}{\Gamma(1/3)} (p)^{-2/3} \qquad (74)$$

Inverting equation (74) and recalling the definition of ξ from equation (69), the mass flux becomes:

$$\dot{m} = \frac{D}{d} C_o \frac{3R_e S_c}{\Gamma(1/3)} \left\{ \int_0^S ds/q(s,\psi) \right\}^{-1/3} \qquad (75)$$

$$\Gamma(1/3) = 2.67894...$$

Equation (75) yields the pickup at each point in a given slot. The quantity actually desired is the total mass pickup. The total mass pickup in a slot $\dot{M}$ is given by:

$$\dot{M} = \int_{-d}^{d} dz \int_0^{\ell} dx \, \dot{m}$$

$$= 2d\ell \int_0^1 dZ \int_0^1 d\tilde{x} \, \dot{m}(\tilde{x},Z) \qquad (76)$$

Now let s and n be coordinates along and normal to a streamline ψ = constant. Then, from equations (75) and (76):

$$\dot{M} = dD\ell\ C_o \frac{(3R^*_e S_c)^{1/3}}{\Gamma(1/3)} \iint ds dn \left\{\int_0^s ds/q(s,\psi)\right\}^{-1/3} \tag{77}$$

Using the fact that $dn = d\psi/q$, and $d\xi = ds/q$, it is possible to carry out the integral along streamlines to obtain:

$$\dot{M} = \frac{2D\ell\ C_o\ (3R^*_e S_c)^{1/3}}{\Gamma(1/3)} \int_0^{\psi_M} d\psi\ \frac{3}{2}\ [\xi(\psi)]^{2/3}$$

$$\xi_M(\psi) = \int_0^{s_M(\psi)} ds/q \tag{78}$$

Here $s_M(\psi)$ denotes integration over the entire distance along each streamline from the point it enters the bottom until the time it exits into the end void (see figure 10). Similarily, ψ_M denotes the maximum value of the stream function, so that the integration covers all streamlines originating in the wall layer.

At this point it is convenient to recapitulate the overall calculation procedure. The first step is the determination of the flow assigned to each slot and to the end void. This is given by equation (19), which yields the total flow in each slot, Q_n, as a function of the total flow drawn through the hold, the hold geometry, and the degree of stratification. The next step is the computation of the pressure gradient along the bottom of each slot containing spill material. This pressure gradient controls the development of the spill material boundary layer, and hence the rate at which spill material is picked up by the ventilation system. The necessary result is given in equation (27). Note that this formula, in turn, requires a knowledge of the variation of the void pressure $\tilde{p}_v$ with height at the open end of each slot in question. The void pressure at any point is given by equation (35), which requires only the information already obtained from equation (19). With the pressure gradient along the slot bottom now determined, the velocity distribution near the slot bottom are given by equations (43-46) and (57). These results are then used to get approximate simplified formulae, equations (63) and (64), which are actually used in the calculation of the rate of pickup of spill material. These latter formulae express the velocities near the bottom of each slot in terms of a "bottom stream function" ψ. Given the quantity ψ, the magnitude of the velocity gradient at each slot bottom, q, can be determined from equation (68). Finally, given q and ψ, equation (77) yields the total mass pickup in each slot $\dot{M}$. These results, summed over all the slots containing spill material, yield the total mass per unit time extracted from the hold by the ventilation system. The computer program which executes these calculations is of necessity quite elaborate. The following sections describe the overall program layout, the principal subroutines, sample results and a complete listing.

8. NUMERICAL PROGRAMS

Two main programs were written. The larger one carries out the numerical calculations of the containership hold ventilation model; while the other plots selected pressures and streamlines. Although the plot program uses CALCOMP emulation subroutines, the program is sufficiently specialized to our computer that it would have limited interest. It will not be described.

8.1 Main Numerical Program

The main numerical program controls the entire calculation, i.e., all subroutines are called from the main program. There are eleven of these. In addition, there are two external function routines. These are called from subroutines. A simple block diagram of the program is shown in figure 11.

The first two subroutines, INTEG1 and INTEG2, carry out numerical integrations related to the flow at the bottom of a slot. In the dimensionless variables used, these are geometry independent. PRINT then tabulates the geometry independent dimensionless slot bottom quantities. Since they do not depend on input data they are carried out once and the results saved for use in all variable geometries to be calculated.

The program is arranged to calculate multiple geometric or thermal cases. The number of these is read (NGEOMS) and a loop entered between CALL INPUT and the end of the main program. INPUT reads, from the input file or device, logical unit 5, the geometric and temperature values to be used. At this point the main program performs two scaling operations, one for the main transverse space (which will be referred to as the "main void" or simply the "void") and the second for the gaps extending fore and aft between stacks of containers (referred to as "intercontainer slots" or simply "slots"). These operations correspond to the quantities ω and $f(\omega)$, defined in equations (6) and (10). The void and the intercontainer slot volumes are assumed to be the only unoccupied space in the hold. For ships with wing tanks, the main void is the volume on the framed side of the transverse bulkhead between the bulkhead and the container stacks. Where there are no wing tanks, the main void is increased in length to account for the volumes between the outermost container stack and the side of the ship. The scaled lengths of the void and slots are then compared to their respective widths to see if the assumptions of the model are satisfied, namely that the scaled widths are less than their lengths. Actually, the widths should be much less than the lengths. If either of these scaled lengths is less than the respective widths, program execution stops with an appropriate message.

The air issuing from the slots into the main void could be a problem to the model if the flow were strong enough to have a jet-like character. In addition, if the slots were spaced close enough together, after scaling, compared to the width of the void they might interact violating another assumption of the model--that the slots are widely spaced. For some actual ship hold geometries this condition may, in fact, be violated. However, the void is not a simple, smooth sided space as assumed by the model but, rather, a complex of interconnected volumes formed by the framing of the bulkhead. It is further broken up by supports for the containers. The structure provides considerable surface for heat exchange and can break up and separate any jets. For practical purposes there seems no way to treat the void correctly in any detail. Accordingly, it was decided to treat it as a simple smooth space as per this model, recognizing that this was questionable. Having made this decision, the scaled slot spacing to void width ratio is computed and printed. If this ratio is not small a warning is also printed.

If the transverse location of the suction aligns with one of the slots there will be numerical problems. Should this occur, the suction is arbitrarily moved away from the slot 1/2% of the void length. This is a distance less than the resolution scale of the overall calculation. Another check looks at the location of the (single) suction to see if it is very near the tank top, Y=0. The calculation assumed it is not. If it is, it is arbitrarily moved up 5 cm. Next, the slots numbers, for the slots furthest and closest to the suction, are determined for later use in plotting pressures and streamlines. It turns out that, even for very small stable stratification temperature differences, the differences in the flow in the several slots is very small, hence only selected results need be displayed to adequately show the flows.

Having completed these housekeeping details, the calculation proper begins. The main calculation is a large loop, passing once around for each slot. Within the loop the slot bottom flow is calculated, SLOT1, and streamlines traced, STRM1. The mass pick-up is then obtained for the separate stream tubes by integrating along the streamlines, PICUP1. Finally, the total mass evaporated from the slot is obtained by integration over all the stream tubes, also PICUP1. This is repeated for each slot and the total mass evaporated obtained by summing the contributions from each slot. In tracing the streamlines, a matrix, ZPSI, giving the transverse location, z(x), for various constant values of slot bottom stream function is formed. This is used in calculating the stream tube integrals and is unique to any given slot. Since the matrix is over-written with each pass through the loop, the ZPSI matrix for two slots--the one closest to the suction and the one furthest from it--are saved as a convenience for later plotting. Upon completion of this calculation for all the slots, results are printed. PRNT1 tabulates the dimensionless slot velocity and stream functions. The axial velocity near the bottom of the slot, USLOT (u of equation (43)), is a function of axial distance along the slot and differs for each slot. This is the axial velocity in the slot just above the boundary layer at the slot bottom. The slot bottom boundary layer velocity approaches USLOT asymptotically with height. The slot bottom stream function defines the track of the air as it passes over and evaporates the spilled liquid assumed to be spread over the hold bottom. Stream function values are tabulated for each slot--the value of the stream function, PSI, for fixed locations along the length of the slot (rows) and fixed locations across the width of the slot (columns). Next the dimensionless mass pick-up for each slot is printed together with the corresponding dimensionless slot location.

The intent in developing this program was to be able to apply the results of the calculation to specific chemicals. Calls are made to INPUT1 where vapor pressure, temperature and diffusivity data are read for the number of chemicals specified in INPUT and NCHEMS. The total mass pick-up, in dimensional form, is computed for the hold ventilation rates read by INPUT2. Note that the mass pick-up varies in an almost trivial way with ventilation rate, the 1/3rd power, so that an eight fold increase in ventilation doubles the mass pick-up. The vapor concentration in the exhaust air is also computed for

SLOT1

SLOT1 is a very short, simple subroutine but, through it use of the external function GRAD, which in turn employs the external function PRESS, involves a fairly complex program structure. The axial flow in a slot depends on the axial pressure gradient. SLOT1 determines the characteristic magnitude of the velocity USLOT, which is the same as $\frac{\partial \tilde{p}}{\partial \tilde{x}}$, near, but not quite at the slot bottom, the first term on the right of equation (45). This term is determined by equation (27). The boundary layer-like analysis of the local flow at the very bottom of the slot detailed in INTEG1 and INTEG2 is scaled to approach asymptotically the velocity USLOT as height increases away from the slot bottom.

GRAD

Subroutine GRAD carries out the integral, equation (27), which gives the pressure gradient just above the hold bottom, $\partial\tilde{p}/\partial\tilde{x}(\tilde{x},0)$, for each slot (needed by subroutine SLOT1 as discussed above). This integral requires the vertical pressure gradient in the end void at the location of the slot, for each slot. This is found by a call to subroutine PRESS. There are two noteworthy aspects of this calculation:

(1) The integrand of the integral carried out in GRAD has an integrable singularity for $x = -1/2$ (the slot void intersection) and $y=0$. Rather than carry out the rather messy algebra to integrate this formally and provide a program option

subtracting the value of UB at Y=0, which is 0, and multiplying the result by 20. Figure 12 shows UB for Z=0 as a function of Y. It is seen to be quite smooth indicating that this approximation should be quite good. Examination of figure 8 shows that this is also true for other values of Z.

INTEG2

INTEG2 forms the indefinite integrals with respect to Z of the quantity UB which yields W, equation (57) and of UBO which yields W_0 again using the trapezodial method. W is shown in figure 9.

PRINT

This is a fairly straightforward tabulation.

INPUT

For each geometry, temperature difference (stratification) data is read. Then hold geometry, as reflected by the main void and slot geometries, is read. Several consistency checks are made: the number of slots must be no more than 11 (dimension statement and format limit) and the number of x values along the slot, NXSLOT, for which values will be computed must not exceed 30 (dimension statement limit). Also the spacing between slots times the number of slots must not exceed the length given for the main void. Failure of any of these tests results in termination of execution with an appropriate message printed. The slot-void intersection locations are calculated placing the slots symmetrically about the centerline of the void. The suction location is then read.

SLOT1

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GRAD

Subroutine GRAD carries out the integral, equation (27), which gives the pressure gradient just above the hold bottom, $\partial\tilde{p}/\partial\tilde{x}(\tilde{x},0)$, for each slot (needed by subroutine SLOT1 as discussed above). This integral requires the vertical pressure gradient in the end void at the location of the slot, for each slot. This is found by a call to subroutine PRESS. There are two noteworthy aspects of this calculation:

(1) The integrand of the integral carried out in GRAD has an integrable singularity for x = -1/2 (the slot void intersection) and y=0. Rather than carry out the rather messy algebra to integrate this formally and provide a program option

to use the alternative algebra, use was made of the fact that the result is smooth as $x = -1/2$ is approached. Numerical experiments for a series of values of x approaching $-1/2$ showed that using $x = -0.498$ gave a result very close to the extrapolated value without encountering numerical problems. $x = -0.499$ gave a value fairly close to the extrapolated one but was suggestive of an approaching numerical problem, see figure 13.

(2) The integral is over an infinite range. The infinite integral is completed by adding an analytically determined piece for argument three to infinity to the trapezodial rule computation from zero to three.

PRESS

The function PRESS is called from GRAD (and also from PPLOT). It computes the pressure at the intersection of the slot at transverse location XS(N) with the main void using equation (35). This pressure depends on the flows from all the other slots.

The calculation involves two pairs of two terms each and, as will be discussed later, has some numerical problems since these terms involve small differences of not very small terms. These problems appear to be large enough to require the use of double precision on 32 bit computers. Figure 14 shows the result of calculating pressure in single precision. A double precision version of PRESS produced smooth plots, compare figure 14 with 20a. Numerical values of the mass pick-up were about 4% lower when using the double precision pressure routine as compared to single precision. Subroutines GRAD and PRESS were originally written by Dr. D. Corley of Montgomery College and NBS.

STRM1

The value of the stream function in the Nth slot at a point X(I) axially along the slot length and z(k) transverse to the slot center line is given by (see equation (64)):

PSI (I,K,N) = USLOT (I,N) *WO(K)

where, as already discussed, USLOT is the characteristic velocity magnitude at this axial position in this slot as tabulated in SLOT1 and WO is the indefinite z integral determined in INTEG2, of UBO, the gradient of the slot bottom velocity determined in INTEG1. The task of STRM1 is to produce, from values of the stream function at fixed geometric points, a table of coordinate pairs (x,z) which correspond to fixed values of stream function. Thus, it is rather analogous to a contour plot routine. The routine chooses an x from the equally spaced ones for which USLOT and WO are known. It determines the PSI value at this x and at the slot edge, z=1. Since flow descends along the slot walls and flows out onto the slot bottom,.streamlines originate at the slot edge. The streamline originating at this x is then followed toward x = -1/2. At each fixed x between the initial one and the far end of the streamline a z is determined, by linear interpolation between the fixed z′s for which WO is available, where the required stream function value is found. The result is a table of z(x) for fixed PSI, ZPSI. Most streamlines terminate at z = -1/2 with a z between 0 and 1. However, especially for slots near the suction and suctions raised above the slot bottom, not all the flow goes directly out the end of the slot. Some of it may return to the slot side wall and flow up the wall to near the height of the suction where it finally leaves the slot. Streamlines for this flow are shown schematically in figure 10. This flow behavior is associated with a maximum in PSI for an x greater than -1/2. To identify the location of the end of a streamline it is useful to record the x location of its end, either -1/2 or the x along the slot sidewall to the left of the maximum PSI where the required stream function value occurs. This is obtained by linear interpolation and recorded in XPSI(N). The matrix of values of ZPSI is returned to the main program and passed forward to PICUPI but is not retained as successive slots are treated.

PICUP1

The mass evaporated from the spill pool at the bottom depends on the velocity and path over the pool. The pick-up integral is given by equation (77). The limits of the integral are set by the extent of the spill. It has been assumed that the spill covers the entire hold bottom so the limits have been made on the wall where the flow enters the slot bottom and either the slot-void junction or the wall, if the flow returns there as described above. It would have been a simple extension of the program to input the extent of the spill pool, presumably less than the full length of the slots and different for each slot, but this seemed to offer little advantage since there is no information on the expected size or extent of a spill. As is done throughout the program, the trapezodial algorithm is used for the integration. Once the separate stream tube integrals have been formed the total mass pick-up for the slot is formed by integrating over the stream tubes.

PRINT1

After all the slot quantities have been calculated the results are tabulated. The values of USLOT are printed in columns for each slot with rows corresponding to axial position X, along the slots. The columns are headed by the dimensionless slot location. The stream function is then tabulated for each slot with columns giving the transverse, Z, location and rows the axial position, X. In this case, slot location is given in dimensional units. This is followed by a short table pairing the dimensionless slot location with the total, dimensionless pick-up for that slot.

INPUT1

In INPUT the counter NCHEMS was set. The main program now loops through INPUT1 reading chemical data for as many materials as requested by NCHEMS. The chemical data entered is the mass diffusivity and partial pressure data using the "Antoine Formula" [14]. The data is then corrected for the case temperature to give the saturation concentration and corrected diffusivity. For each chemical, several flows can be used. The effect of flow is very simple but this feature was included as a convenience. The number of flows to be considered for each chemical is read, NFLOWS.

INPUT2

This simply reads the flow and returns. It is called as many times as requested by NFLOWS.

PPLOT

The pressure at the slot-void intersection for the same pair of slots for which streamline data was saved in STRM1 is now calculated using the external function PRESS. This is done separately rather than saving values computed during the slot calculation to provide some additional flexibility in the range of values computed. The cost in computing time is not great.

8.3 Input Data

A sample input data file is given in appendix 1. The example is for a single case with a ΔT of $0.1^{o}C$. The length of the main void (in this case the width of the hold plus twice the container length to simulate a ship without wing tanks) is 51 m, its width (fore and aft dimension is 0.8 m and its height 20 m. The intercontainer slots are 12 m long (fore and aft), 0.1 m wide spaced 2.46 m along the length of the main void. Since the slots are the same height as the main void their height need not be input. Twenty points are calculated along the length of the slots and there are 11 slots. The suction is placed at and a nominal height = 0.6 m and transverse location relative to the center line of the main void of 0.0. The hold empty volume is 2407 m^3 and the void volume is 1920 m^3. One chemical is considered. The caption is for this chemical; the caption is limited to one line of 80 characters, maximum. Chemical data entered is:

Mass diffusivity of spill vapor at $0^{\circ}C$ cm^2/sec

Molecular weight of spill chemical

Material constant, B of Antoine's formula, $^{\circ}K$

Temperature at which spill chemical has a vapor pressure of 1 atm $^{\circ}C$

Reference temperature, C of Antoine's formula, $^{\circ}K$

Ambient temperature at spill liquid, $^{\circ}C$

One flow is considered and the flow is 1.0 m^3/sec. The result of executing the program (in double precision) with this input is reproduced in appendix 2.

9. NUMERICAL RESULTS

The purpose of this study was to predict the mass evaporation rate for a hazardous liquid spill in a containership hold. Since no information was available about the extent of such a spill, it was assumed that the liquid would spread uniformly over the bottom of the hold (tank top). In practice, there is almost always some trim to the ship so that liquid would tend to drain to the aft end of the hold. A low point sump could collect some of the liquid which might be advantageously pumped to a safe place thus reducing the amount of liquid that would have to be removed by the rather slow evaporation process. Rolling of the ship would tend to spread the spill across the entire width of the hold. As discussed in the section of this report describing the numerical programs, the spill was assumed to extend fore and aft along the entire length of the intercontainer slots and athwart ships across all the slots. However, no evaporation was computed for the main void comprising the transverse space between the bulkhead and the end of the container stacks. Unless otherwise noted the calculations were done for a hold containing twelve stacks of 12 m (40 foot) long containers and with eleven intercontainer slots 0.1 m wide. The container width was 2.36 m, giving slot spacing of 2.46 m. The air temperature near the bottom of the hold was taken as 10°C. Dimensional mass evaporation rates are based on vapor pressure and diffusivity data for heptane. Calculations for numerous other fuels have been made by Sealand Corp. (using a slightly less general model) and are reported elsewhere [1].

Calculations were made for various locations of a single suction pipe, for several air flow rates and several stable stratification temperatures. The effect of varying the height of the suction above the tank top is shown in figure 15 for a suction on the centerline of an idealized ship. Raising the suction from .05 m above the tank top to 1.5 meters is seen to decrease the evaporation rate by a factor of 3-1/4 for a stable stratification of 0.1°C over the hold height of 20 m. Since the evaporation rate varies as flow to the third power, to remove liquid with the suction at 1.5 meters at the same rate as with it at .05 m the flow would have to be somewhat more than 34 times as great for the 1.5 meter height (3.25 cubed). For a 1°C stable stratification this effect of suction height is seen, from figure 17, to be very much more pronounced.

Moving the suction laterally at constant height has comparatively little effect. This is illustrated in table 2 which lists the dimensionless mass pick-up for two suction locations, one on the centerline and the other near one side of the ship. Figure 16 presents the same information graphically. However, since this calculation fails to account for the interference to transverse flow occasioned by the vertical framing of the bulkhead, these results should be viewed with caution. Figure 17-a shows the calculated pressure at the open ends of a pair of slots, one on the hold centerline (solid line), the other the last slot outboard (dots). Pressures for two suction heights are shown, .05 m, figure 17-a and 0.6 m, figure 17-b. Note that, except for a region of about 0.2 dimensionless units around the height of the suction, the pressures are essentially the same for the two slot locations at a given suction height. Since the slot flow is determined primarily by the gradient of the pressure at y=0, little difference in the slot flows should be expected. This is reflected in the data presented in table 2. Note also the effect on the pressures below the suction of raising it, i.e., compare, in figures 17-a and 17-b, the pressure behavior below the pressure "spike". In figure 17-b, the pressure gradient is small between the tank top, y=0, and a dimensionless height of about 0.1 (dimensional height 0.2 m). The very small pressure gradient at y=0 results in little flow adjacent to the tank top and little scavenging of the flammable vapors. This accounts for the behavior shown in figure 15 of mass removal rate with suction height.

Streamlines corresponding to the two sets of paired pressure distributions, figure 17a and 17b, are shown in figures 18-a,b and figures 19-a,b. In these, the transverse scale has been expanded about 100 times relative to the longitudinal scale. The drawings should be very attenuated in width to properly represent the geometry but, if so presented, would be unreadable. The first pair, figure 18, show the streamlines for the boundary layer flow at the bottom of the slots for the suction only .05 m above the tank top. A thin layer of gas flows down the sides of the containers and spreads out over the slot bottom--streamlines originating at the sides. It turns and flows along the slot bottom toward the open end of the slot. For the slot closest to the suction the streamlines are strongly bunched in the center of the slot. For the slot farthest away from the suction the behavior is similar but the bunching of the streamlines near the centerline of the slot is less pronounced. As the suction is raised there is quite a noticeable change in the flow which becomes more marked as the suction is raised. This change is seen by comparing figures 18-a and 19-a. With the suction raised, not all the flow leaves the slot along its bottom surface. Some returns to the container sides and flows up, turning toward the main void as it approaches the height of the suction. By the same score, not all the flow descends in the thermal boundary layer next to the container sides to the slot bottom although it does toward the rear of the slot. Some of the flow near the opening into the void turns as it approaches the height of the suction and exits directly. This flow is shown schematically in figure 10. Note that flow descending all the way to the tank top has actually been over cooled. In the stably stratified situation pertaining, it must be warmed again in order to rise to the height of the suction. To gain heat it must pass close to either the walls of the main void or of the slot. Obviously, for the suction raised well above the tank top, some of the air finds it easier to seek the slot side wall rather than the main void walls. This flow behavior was found through the numerical calculation. Although it is completely plausible , it was not anticipated. As the suction is further raised the flow along the slot bottom becomes still weaker and the tendency to return to the wall decreases. It has almost completely dissappeared with the suction at 1 m, figures 20a, b, and c.

The effect of increasing the stable thermal stratification is seen by comparing figures 17-a and 21. Note the different ordinate scales of the pressure plots. In figures 17-a the temperature difference over the 20 m hold height is $0.1^{o}C$ while it is $1.0^{o}C$ in figure 21. The dimensional suction heights are the same but, due to the greater thermal stratification, the dimensionless height at $\Delta T = 1.0^{o}C$ is greater. In general, the effect of increasing ΔT is to compress the vertical scale of the flow. With a higher ΔT the same vertical suction height appears to the flow as further from the tank top.

Increasing the stable temperature stratification acentuates the flow effects as shown in figures 18, 19, and 20. The flow in the slot closest to the suction bunches strongly but then spreads rapidly as the mouth of the slot is approached, figure 21-b. Even with this low suction location some flow, driven by the stronger stratification, returns to the wall. The flow in the slot furthest from the suction is less strongly affected, figure 21-c.

The main computed results for a given hold configuration and temperature stratification are expressed in dimensionless form for a nominal temperature of $10^{o}C$. To obtain dimensional output the ventilation flow and spill liquid partial pressure and diffusivity are needed. Some vapor pressure data as a function of temperature can be found in the literature [2] and, typically, the log of the vapor pressure is nearly linear with 1/T as shown for heptane in figure 2. Although the theory for vapor pressure is very well developed [15], a much simpler semi-empirical approach, Antoine's formula, is found in Hirata, Oke and Nagahame [14]:

$$\log p = A = B/(C + T)$$

where p is the partial pressure, T temperature and A, B, C constants unique to the particular chemical. Further, since Hirata et al give values for these constants for a large number of chemicals their approach was used. Diffusivity data was corrected for temperature using the empirical relation given in [16].

It is clear from figure 2 that the equilibrium vapor concentration is a strong function of temperature. The numerical calculation obtains the concentration for the input value of slot bottom temperature. However, the flow, which depends strongly on the differential stratification temperature, but only weakly on average ambient temperature, is computed using a nominal ambient.

10. EXPERIMENTAL PROGRAM

An approximately 1/12 scale model of a much simplified containership hold was built. It consisted of a box with inside dimensions 1.22 m long x 2.66 m wide x 1.68 m high built of 0.65 cm fir plywood and 0.6 mm galvanized steel. To simulate the cooling effect of seawater on the hull, the bottom and lower 74 cm of the two ends were steel, maintained at constant temperature by circulating temperature controlled water through copper tubes soldered to the steel. The remainder of the apparatus was of wood, and allowed to seek room temperature. The apparatus was in a large temperature controlled room where typically the temperature varied between 18 and 25^{o}C with an average value of 23^{o}C during the course of a day. Inside this "hold" were three plywood boxes 1.51 m high x 1.02 m long. The center box was 0.81 m wide and the two outer boxes 0.61 m wide. These simulated stacks of containers. These three boxes were positioned to give two slots 4 cm wide between them and 2 cm wide slots between them and the sides of the hold. All three were centered between the long sides of the hold leaving two transverse voids 10 cm wide (fore and aft). All the plywood surfaces were coated with epoxy base paint to prevent take-up of the spill vapors. A simplified cross section of the apparatus is shown in figure 22.

The flammable spill was represented by a shallow pan filled with an ethyl alcohol-water mixture. The pan was 1.16 x 2.39 x 0.025 m and held about 40 liters of mixture. The pan was placed in the "hold" and the simulated container stacks set in on pads 0.031 m high to allow the liquid to pass freely under them. The choice of a water alcohol mixture as the spill liquid was unfortunate. It was made for safety reasons. The flammable gas detector to be used could detect the alcohol vapors at concentrations well below their flammable limit and mixtures and temperatures were chosen so that only nonflammable mixtures would exist. The mixtures themselves were too dilute to support combustion. However, the concentration of the mixture was difficult to control and changed substantially during the course of a test. Thus, there was constant uncertainty about the equilibrium vapor pressure of the spill liquid.

Reducing the physical scale requires that the initial temperature difference be increased if similar flow conditions are to prevail. The dimensionless Grashof Number, $GR = (gd^3/\nu^2)(\Delta T/To)(d/h)Pr$, must be kept constant. With a 1/12 reduction in physical size the ratio d/h was increased but, in the model, the temperature difference top to bottom for similar stable stratification should be increased by a factor of 90. In practice a temperature difference of about 15°C could be achieved, equivalent to a full-scale temperature difference, ΔT, of only 15/90 = 0.17°C. Calculations in the previous section were for ΔT's of 0.1 and 1.0°C. The stable situations tested are for weak stratification compared to full scale. For the unstable case, model temperature difference of only 5°C was achieved. Thus the full scale instability simulated was quite weak.

Due to the limited budget and time, no air flow measurements inside the "hold" were attempted so it was never established if the actual flows resembled those predicted by the calculations nor if there were significant circulating flows, as might arise from a transverse temperature gradient. Some tests were run in the configuration shown in figure 22 and some with the inlet and exhaust connections reversed. For all tests the cooling water was turned on and adjusted to the test conditions the day before the spill liquid was to be loaded and data taken.

Results for a stably stratified condition are shown in figure 23 for several air change rates. Note, however that, again a scaling factor enters, model air changes per hour are not the same as full-scale. The behavior during the first 15-30 minutes is erratic because of the transients associated with loading the liquid in the pan, achieving steady liquid temperature and ventilation conditions. The qualitative trend after 30 minutes, for both suction locations, is to reduce the combustible vapor concentration in the exhaust as air flow is increased. With the exhaust at the bottom, significantly more vapor is removed than with it at the top for the same air change rate.

When the behavior with a stable temperature gradient is compared to that with an unstable gradient, it is necessary to recall that, in this apparatus, the upper portion was always nominaly at room temperature. When a stable temperature gradient was called for, the lower portion and the liquid pan were cooled; when an unstable gradient was desired they were warmed. Thus, with the same spill liquid, the equilibrium vapor concentration in the stable case (cool liquid) was considerably less than for the unstable case (warm liquid). At zero air changes per hour a survey of vapor concentration versus height showed little variation. At 1 air change per hour with a bottom exhaust for the unstable case the vapor concentration, except very close to the surface of the pan, was quite uniform and about 40% of its equilibrium value. For the stably stratified case the vapor concentration decreased near the pan more slowly with height than in the unstable case but leveled out at about 30% of its equilibrium value about 10 cm above the bottom and decreased slowly with height above that, figure 24. Shifting the exhaust from the center to one end had no effect to the accuracy of these tests. The behavior in the stably stratified case suggest that a significant secondary mixing flow was present, but that a mild degree of stability was achieved.

Overall the experimental results were ambiguous to mildly encouraging. They also illustrate the inadvisability of conducting convection experiments hastily and with a tight budget. The experimental apparatus was built by Mr. W. Bailey and the data taken by Mr. S. Steel, both of NBS.

11. CONCLUSIONS

One of the more interesting aspects of this study of a significant hazard to shipping was the almost total lack of previous scientific research at the time the initial decision of the International Maritime Consultative Organization relative to containership ventilation was made. Our limited study revealed many unanswered questions about fluid flow and heat and mass transfer in the context of maritime safety. It shed some light on one particular situation -- the ventilation of a stably stratified containership hold. Many assumptions had to be made -- when a surface temperature was needed, we assumed it was known, when geometric simplifications had to be made, it was assumed that associated complicated flow phenomena were not present. Despite these simplifications and idealizations, the work reported here is, to the best of our knowledge, the only analysis in existence that attempts to study the efficiency of ventilation in a realistic hold geometry and thermal environment.

Although much more detailed research should be done on a variety of specific points, we believe that some important conclusions can be drawn from our study and that these conclusions will stand the test of time.

(1) In a stably stratified containership hold, almost all the extracting capability of a ventilation system will be concentrated at the vertical level of the suction.

(2) In order to extract any significant amount of spilled material, it is essential to place the suction as close to the hold bottom as is feasible.

(3) With few exceptions, the natural tendency of vapors from spilled liquids will be to concentrate near the hold bottom. Therefore it is not efficient to try to design the ventilation system so as to mix the gas throughout the hold.

(4) Ventilation expressed simply as air changes per hour (for some arbitrary hold loading condition -- empty or full) is a poor measure of performance. The performance will be sensitive to the thermal environment, degree of stratification and spacing between containers.

(5) The lack of the ability to analyze the thermal environment of a containership hold is a major impediment to systematic study of hold ventilation. There is important need for research in this area.

12. REFERENCES

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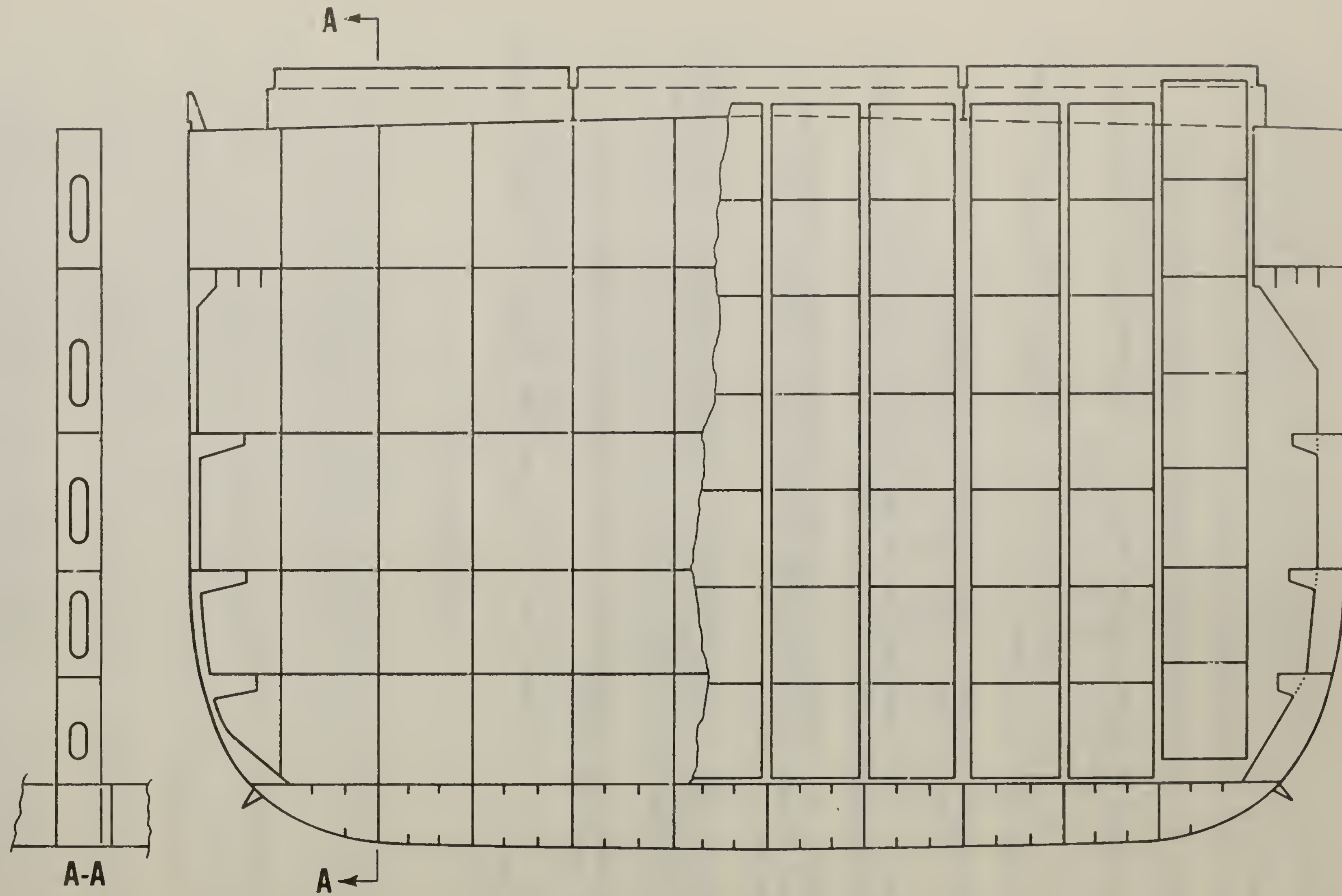

Figure 1. Cross section of a typical containership near its mid section. To the right is shown the container stacking and to the left the bulkhead framing

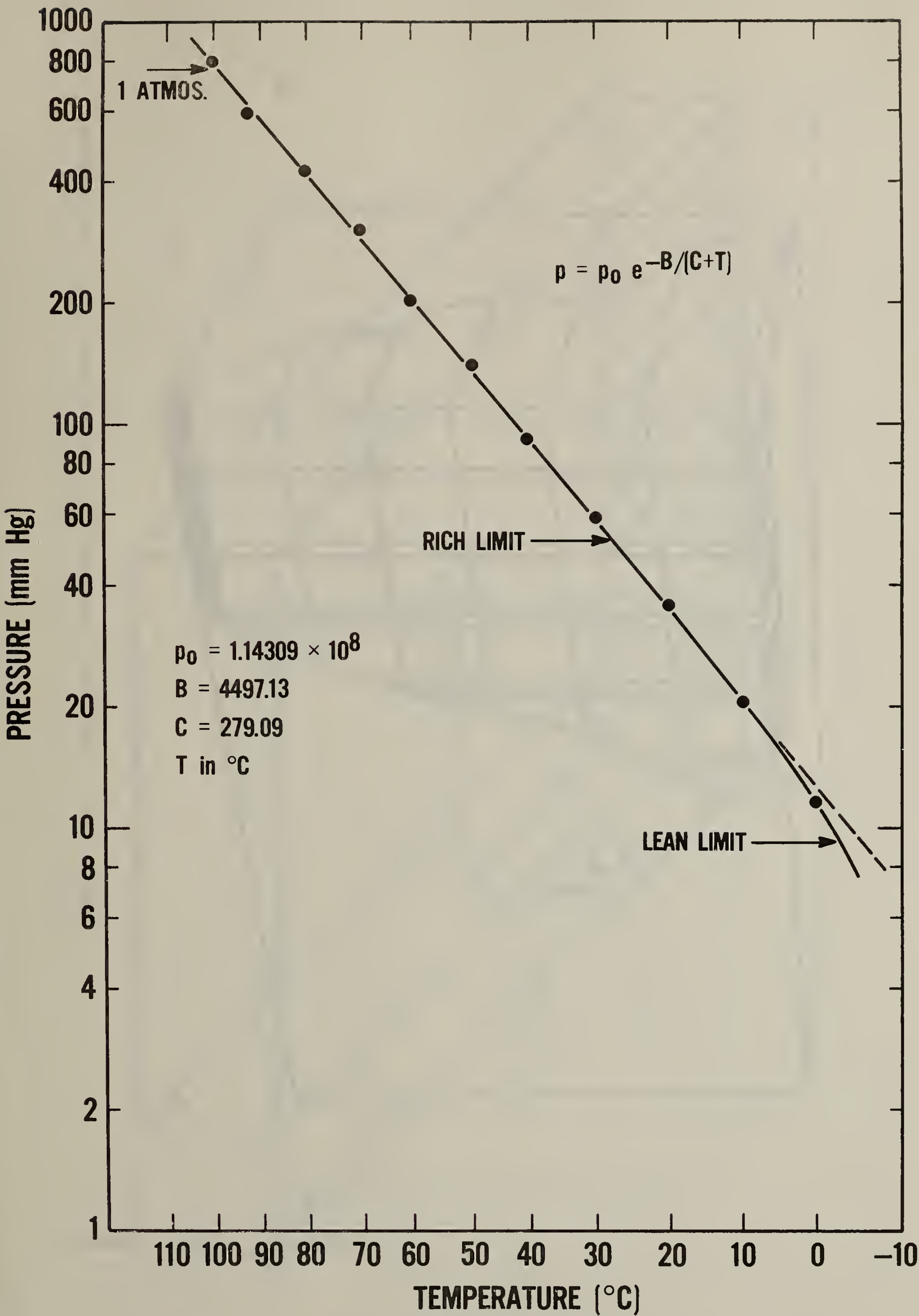

Figure 2. Vapor pressure versus temperature for heptane. Rich and lean limits are for an air environment

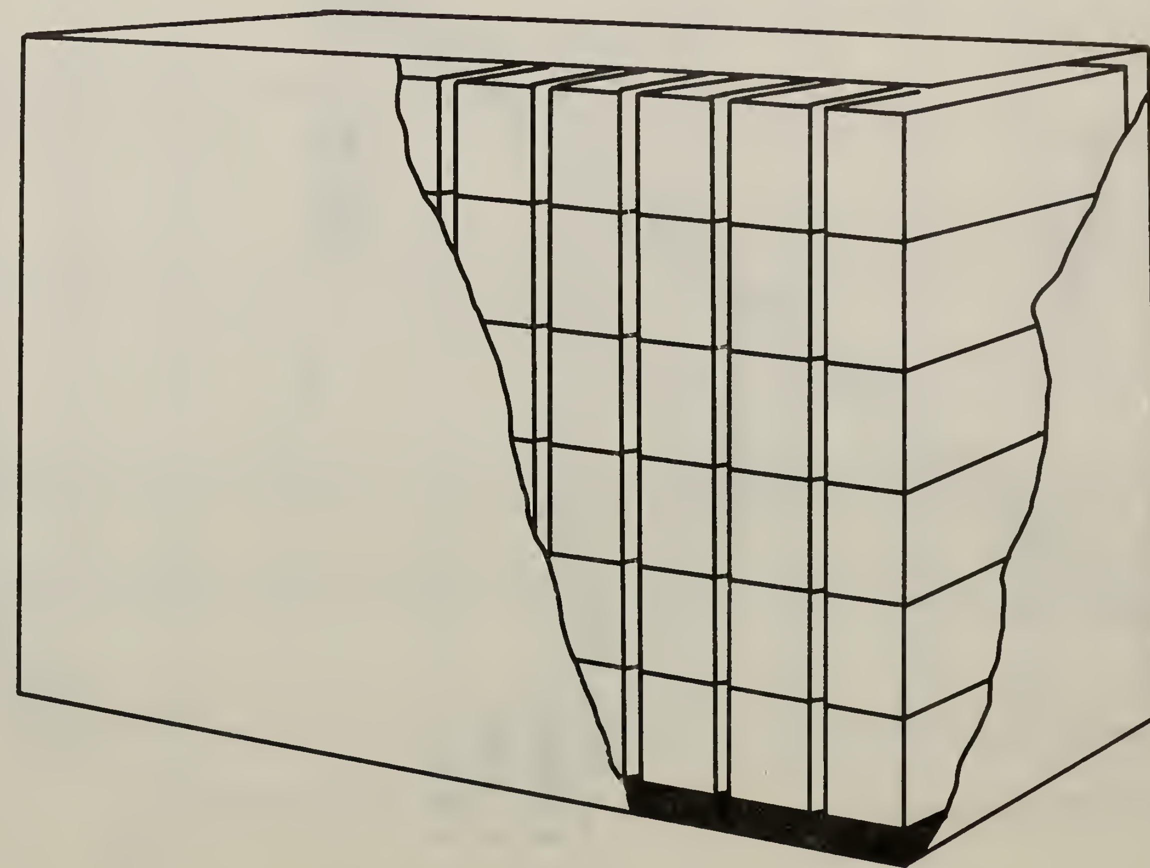

Figure 3. Idealized containership hold loaded with containers

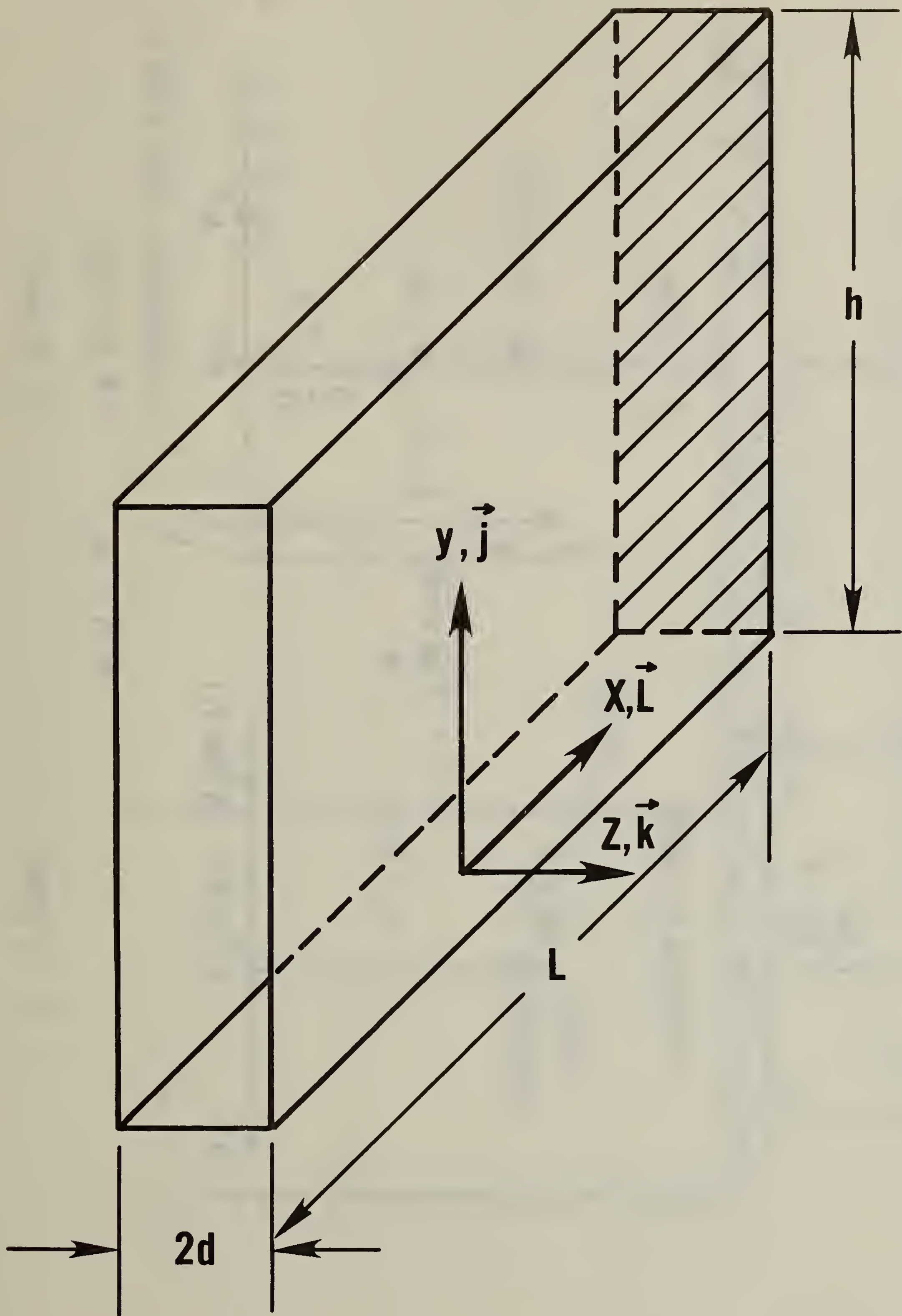

Figure 4. Geometry of the space between two stacks of containers (inter-container slot)

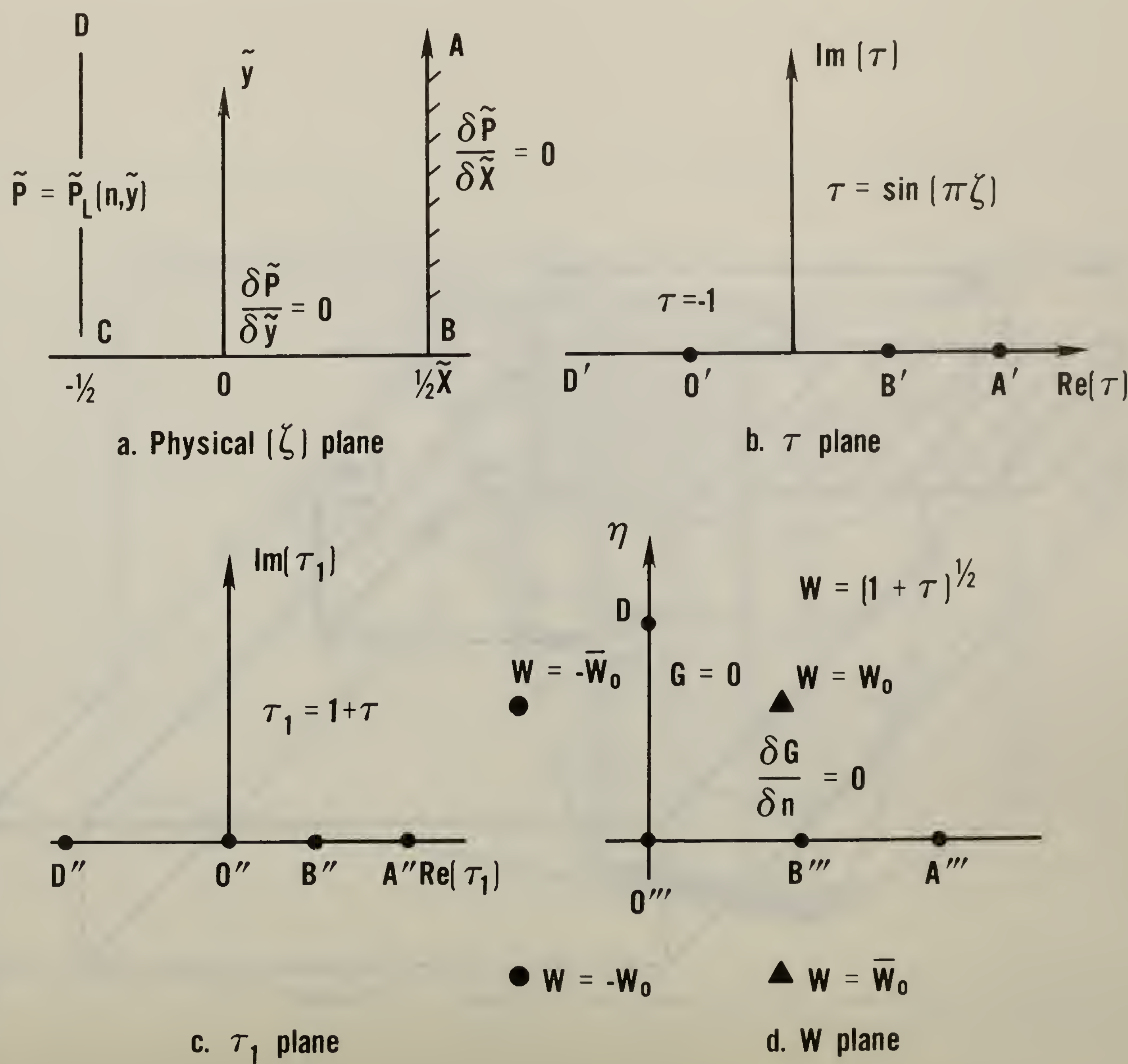

Figure 5. Conformal mappings used to obtain the Greens function, G, in equation 24

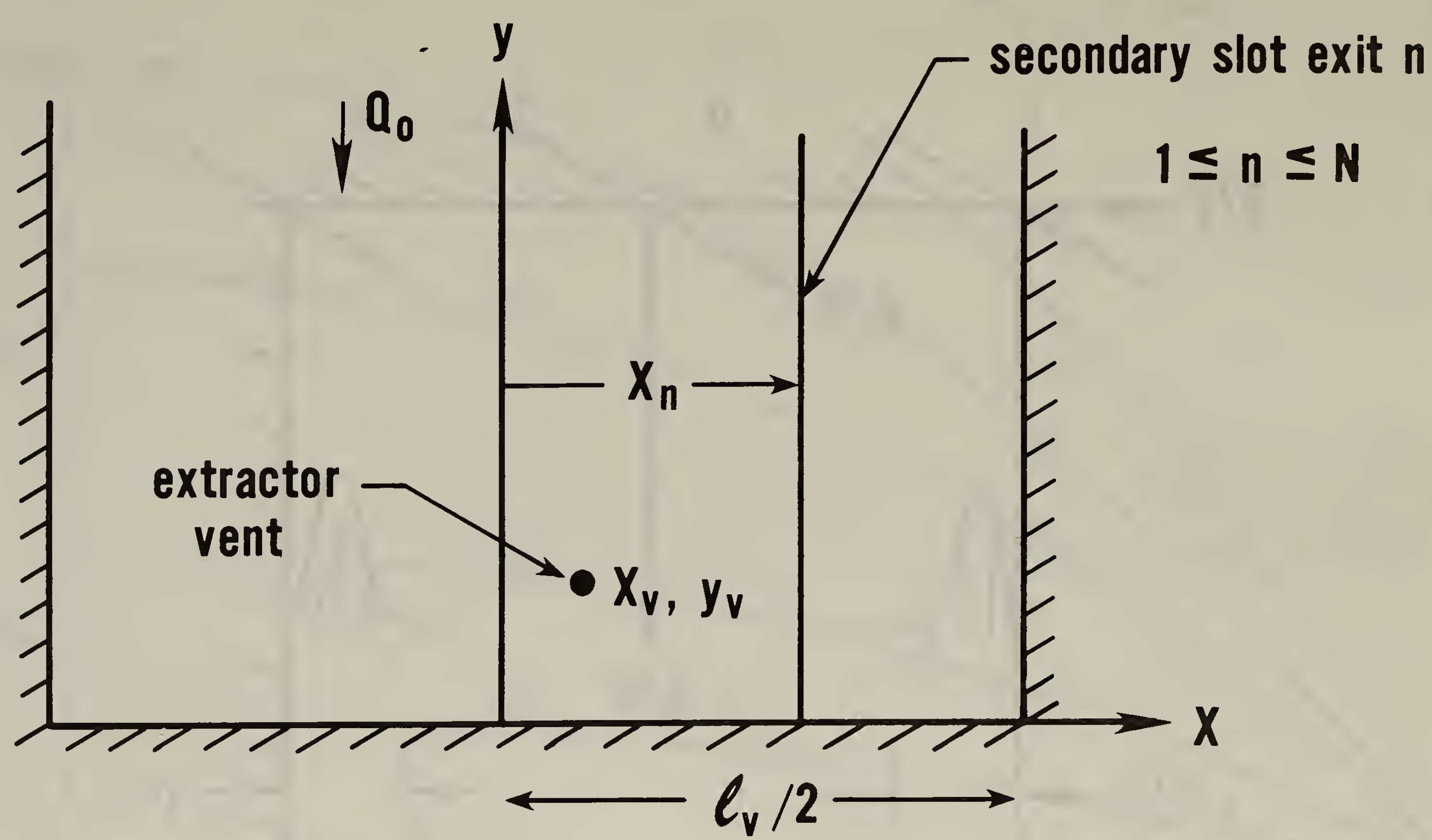

Figure 6. Plan view to the end void showing the location of the forced ventilation extraction point (suction). Ventilation flow enters from the top of the void and from the intercontainer slots (one of N slots indicated by a vertical line)

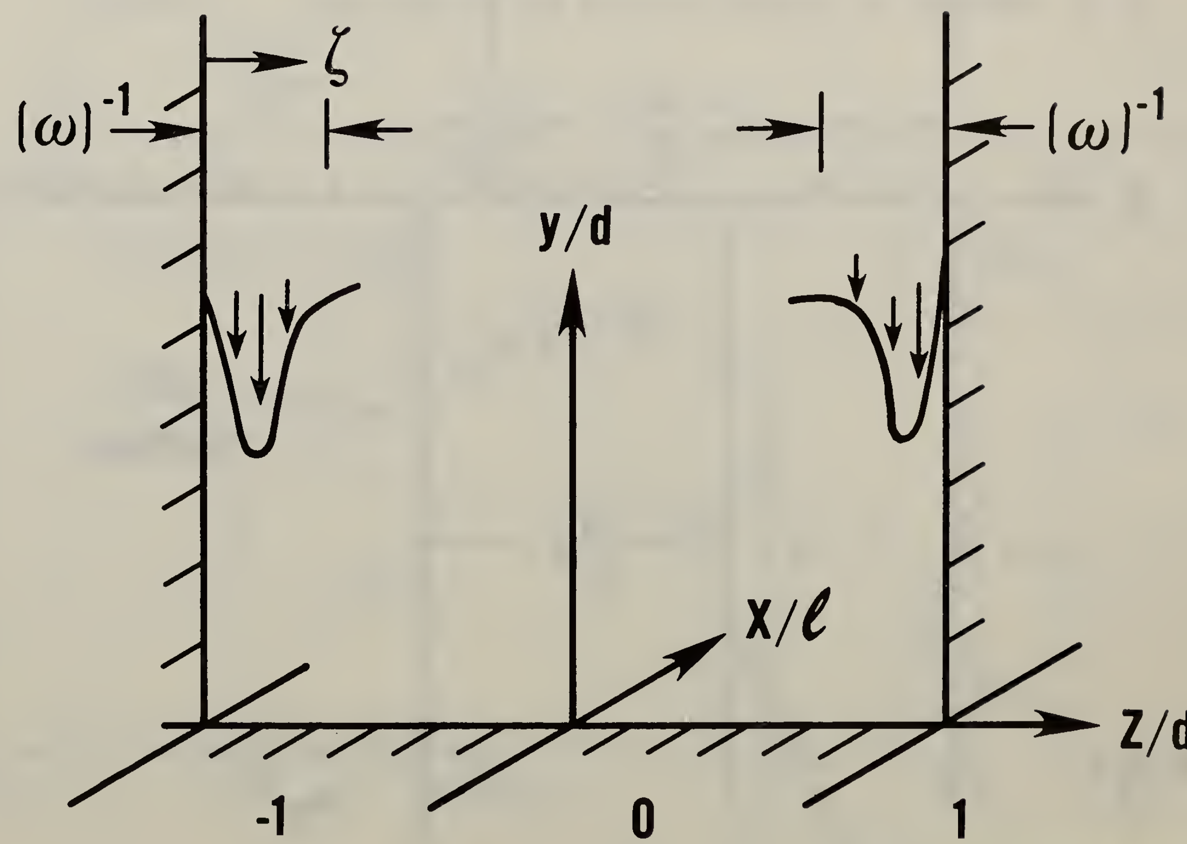

Figure 7. Cross section of the bottom of an intercontainer slot. Velocity distribution of the gas as it approaches the slot bottom is indicated next to each wall

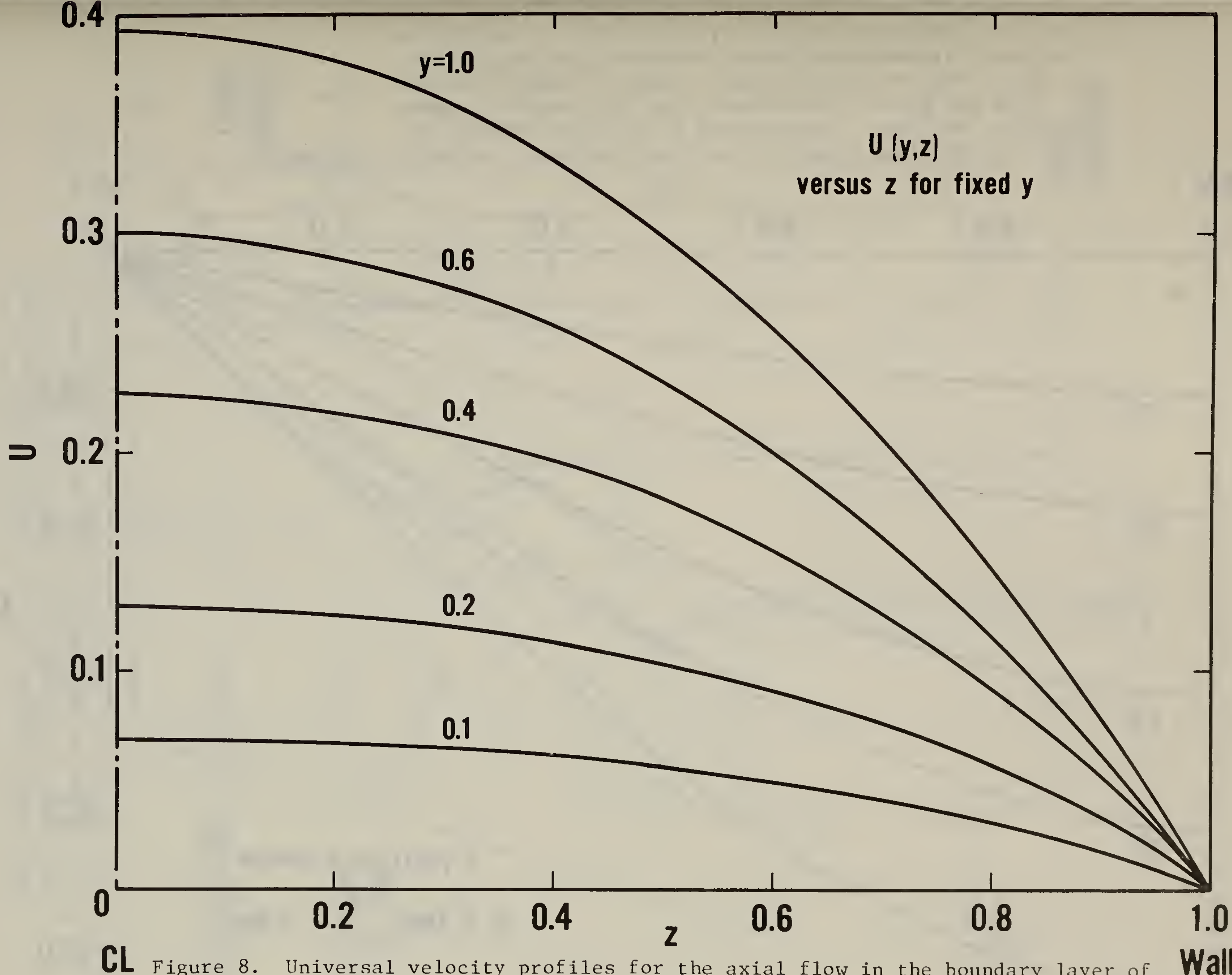

Figure 8. Universal velocity profiles for the axial flow in the boundary layer of a slot bottom. The flow is symmetrical about the slot centerline so only one half the slot width is shown. The velocity is zero at the slot bottom and increases toward an asymptotic profile as height, y, above the bottom increases.

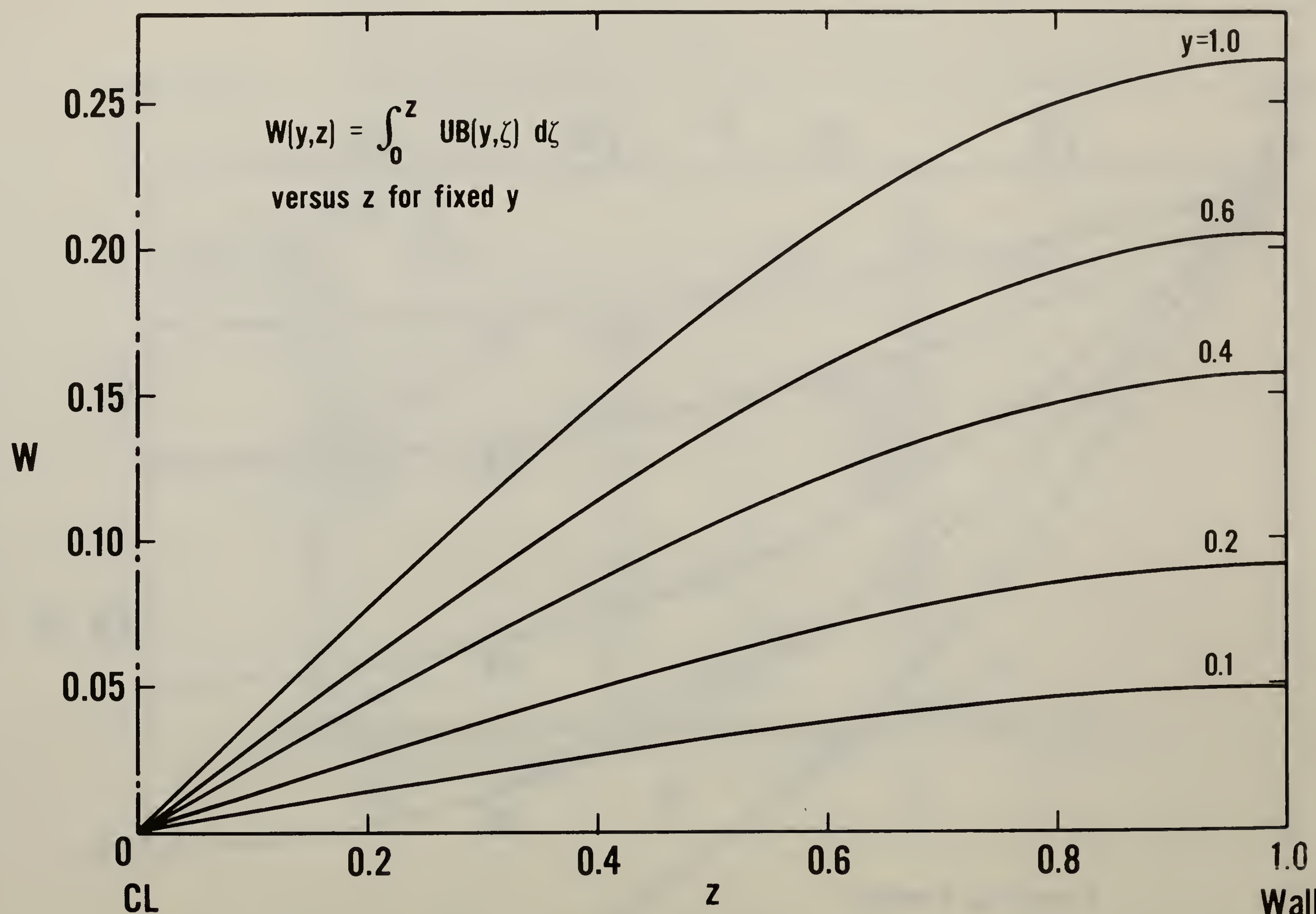

Figure 9. Universal velocity profiles for the transverse flow in the boundary layer of a slot bottom. The flow is anti-symmetric about the slot centerline so only one half the slot width is shown. The velocity is zero at the slot bottom and increases toward an asymptotic profile as height, y, above the slot bottom increases

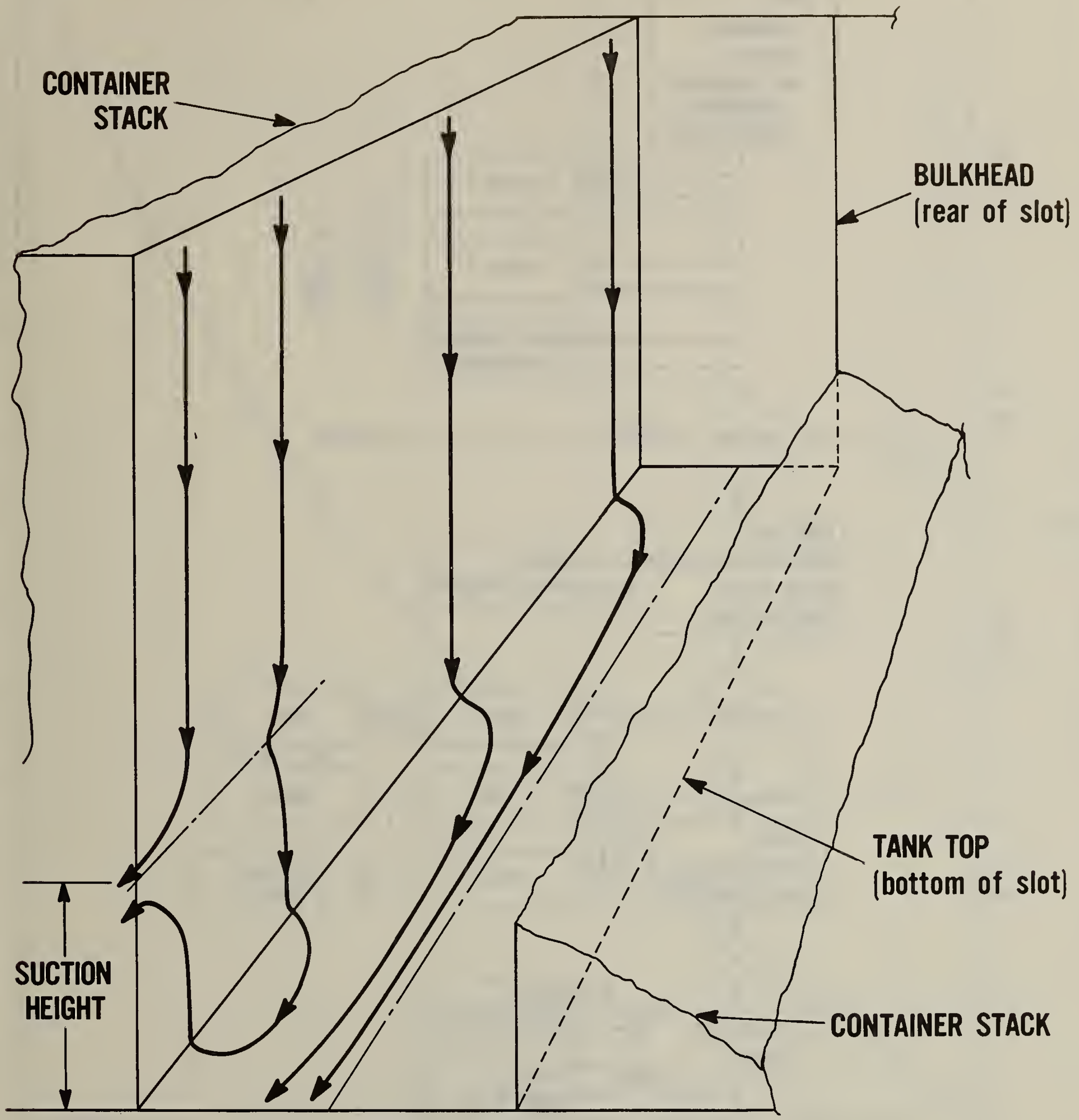

Figure 10. Perspective sketch of an intercontainer slot showing air flow streamlines. The air picks up evaporated spill vapor as it moves in the boundary layer along the bottom of the slot

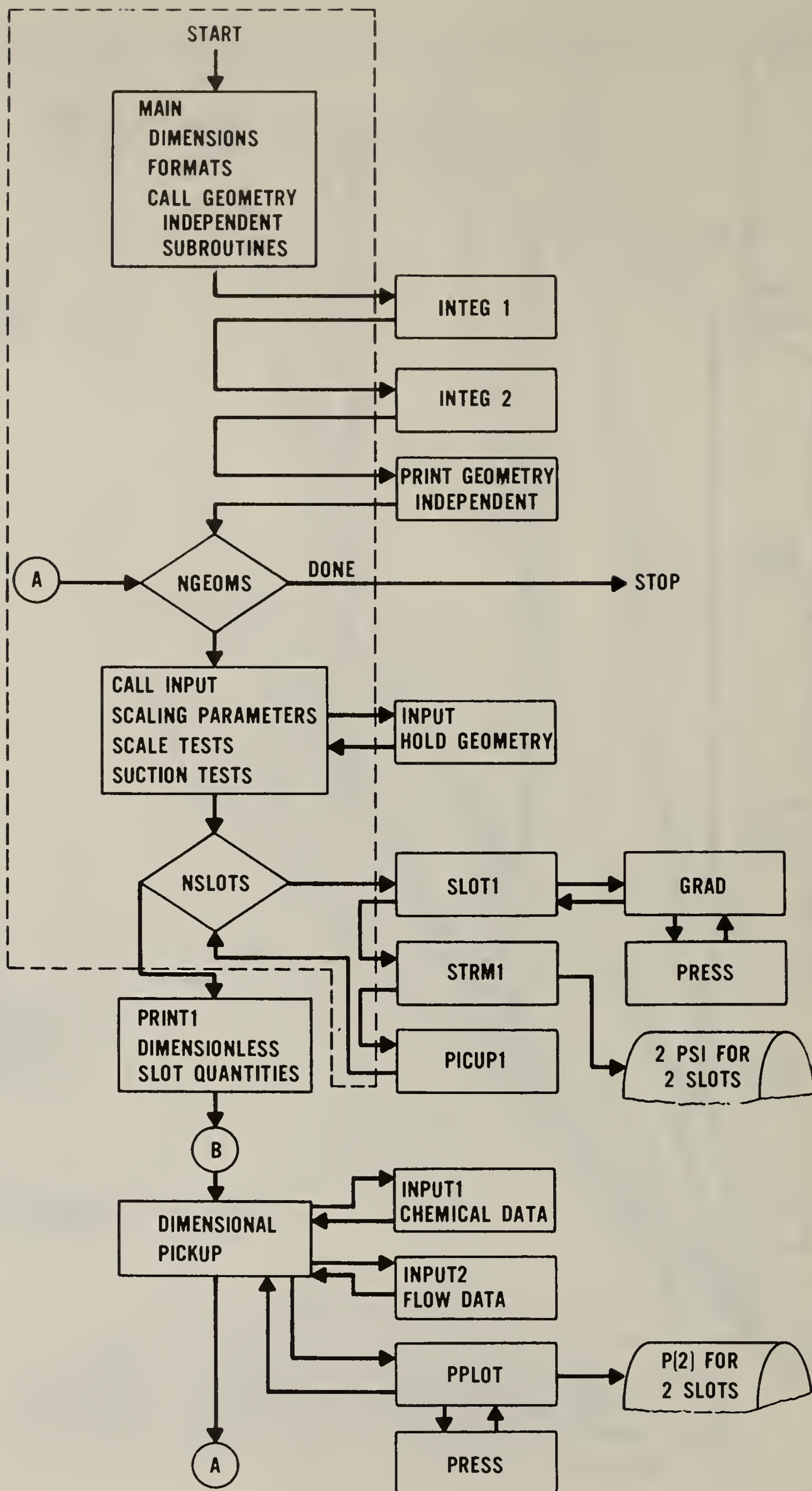

Figure 11. Simplified flow diagram for the computer program

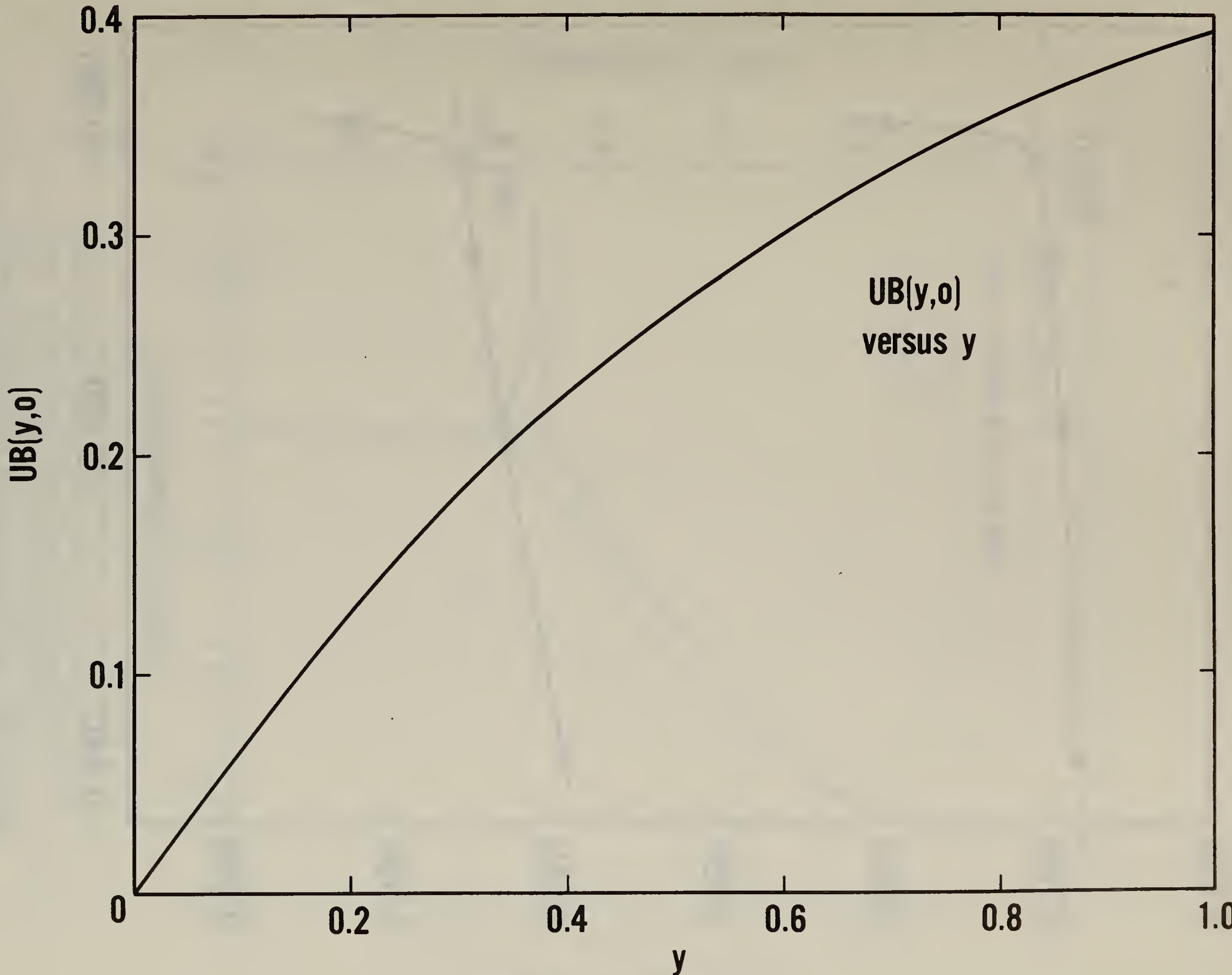

Figure 12. Universal slot bottom axial velocity plotted versus height for a fixed transverse location (centerline)

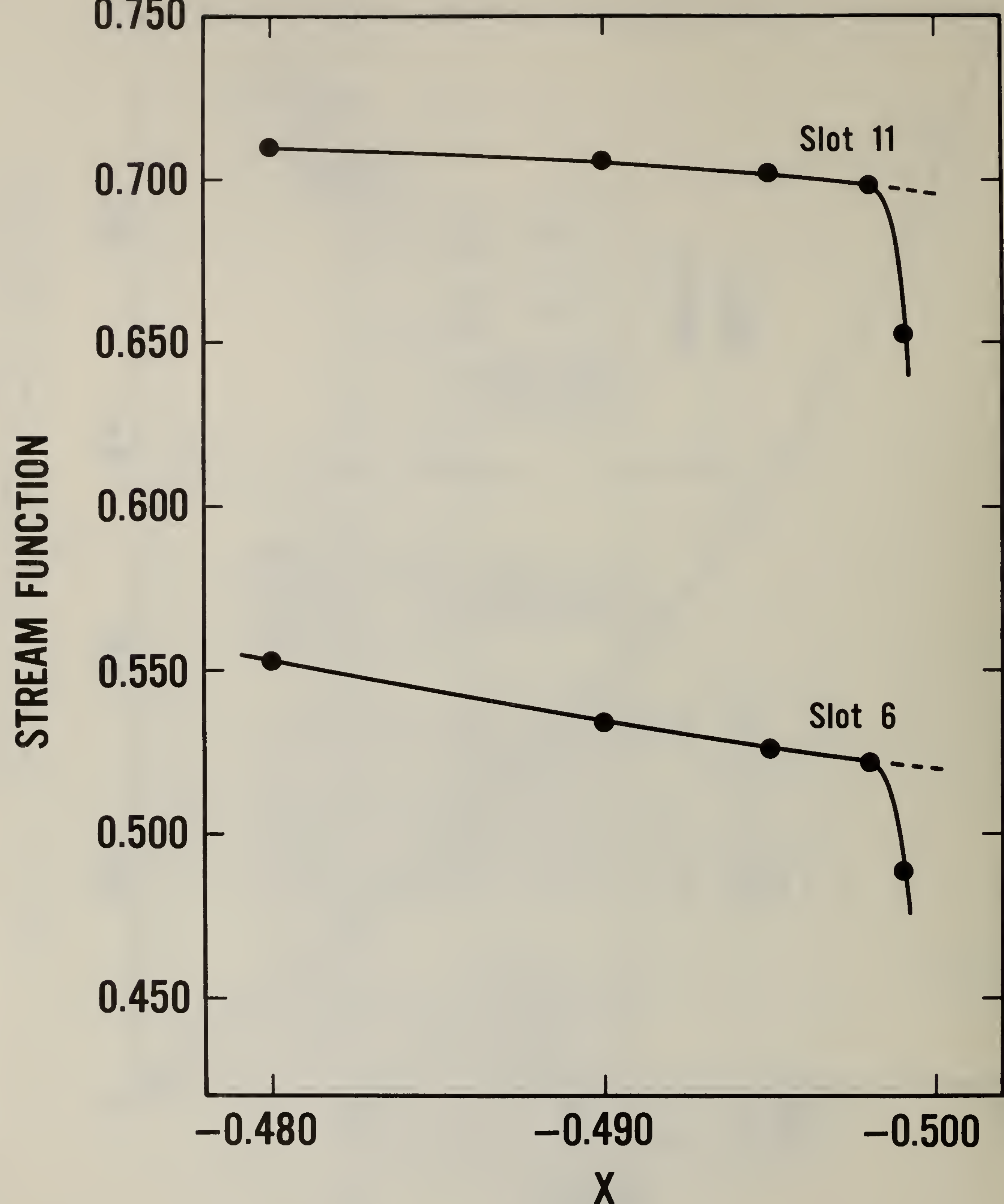

Figure 13. Slot bottom stream function near the intersection of the slot with the hold end void as a function of distance from the intersection (at x = −1/2)

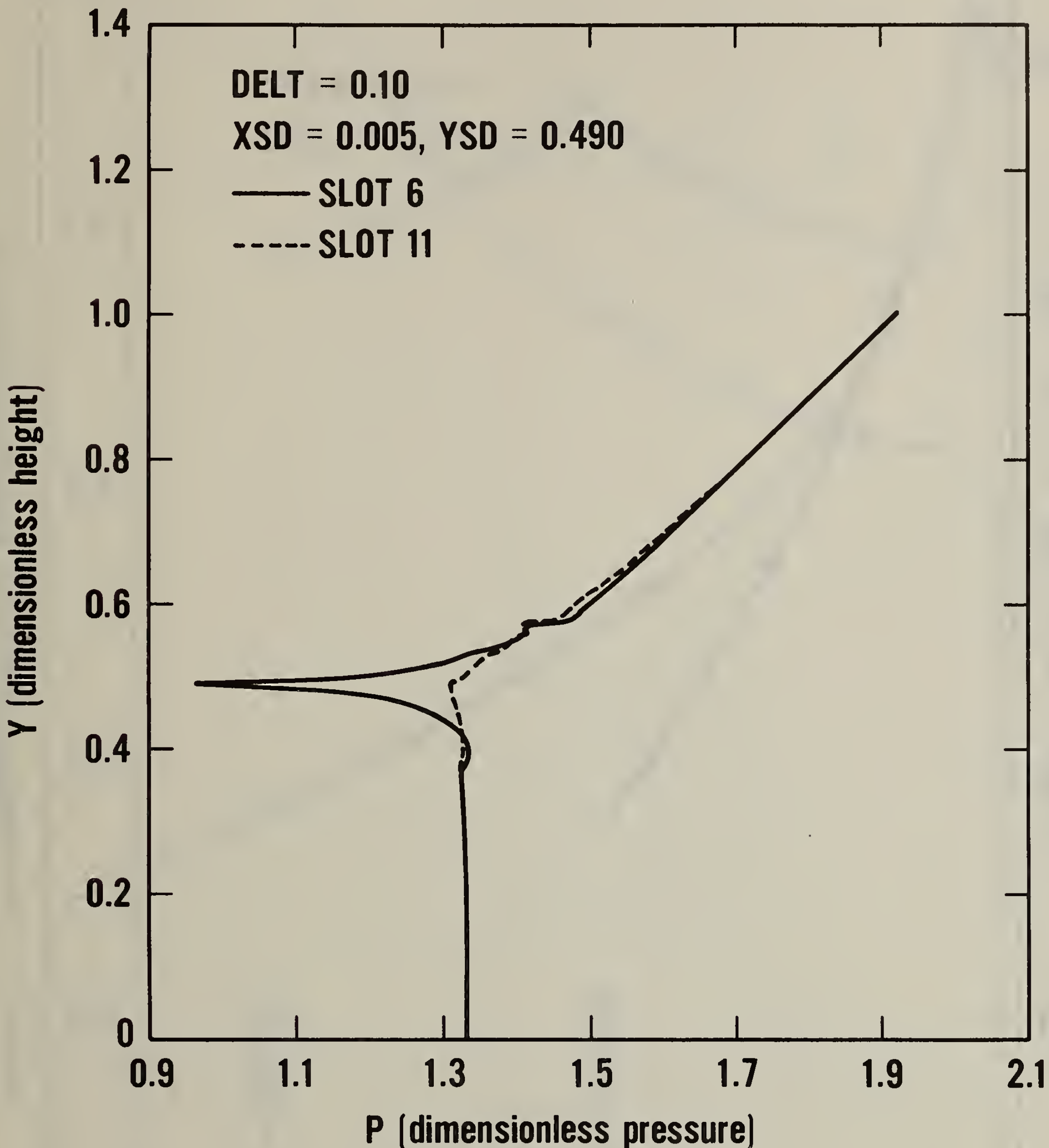

Figure 14. Dimensionless slot pressure as a function of dimensionless height above the slot bottom for two slots: solid line, slot nearest the suction and dotted line, slot furthest from the suction. Pressures calculated single precision. Compare with figure 20-a which is the same case calculated in double-precision

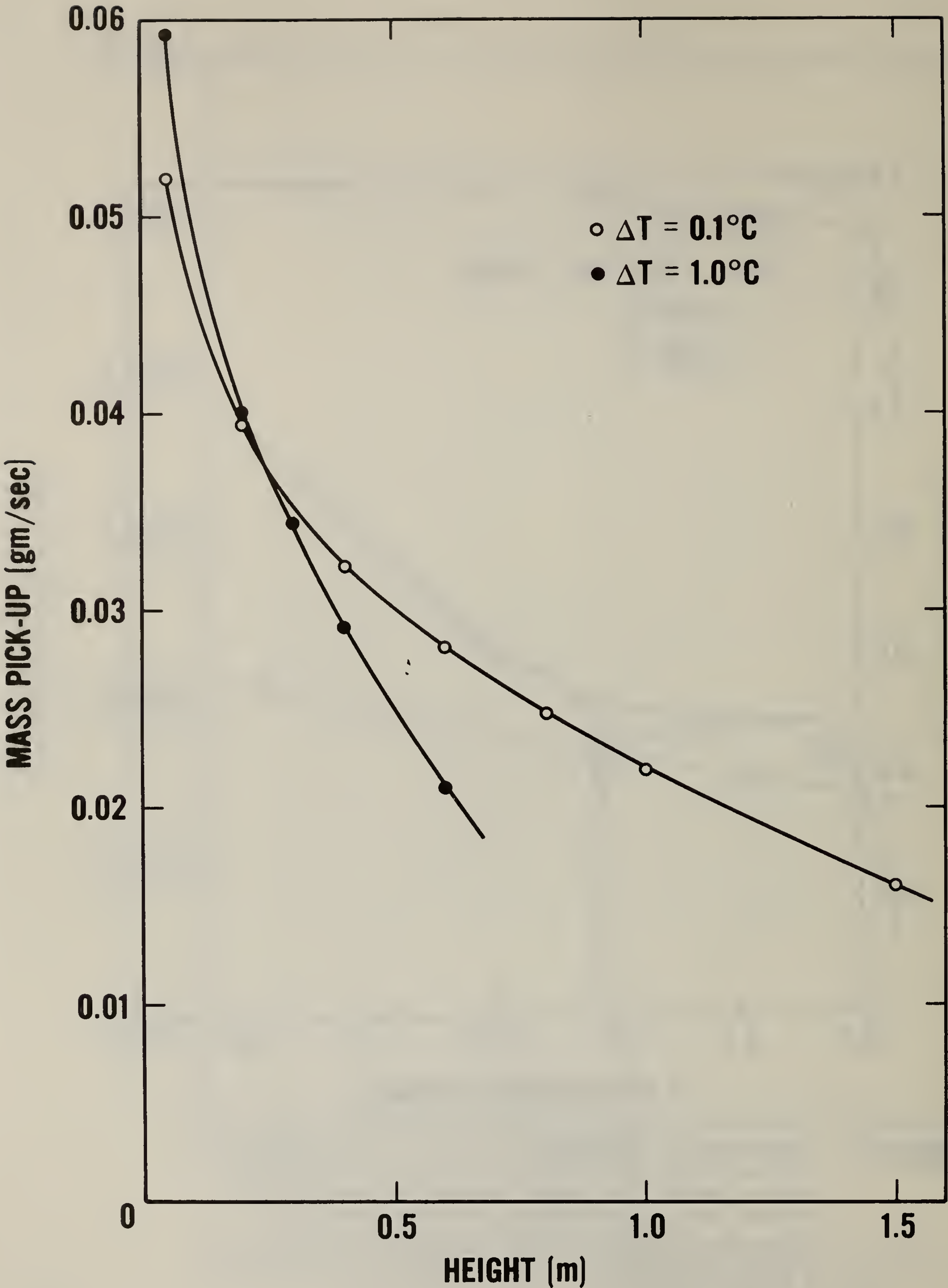

Figure 15. Computed mass pick-up by evaporation and removal by forced ventilation as a function of suction height above the slot bottom for two different amounts of stable stratification

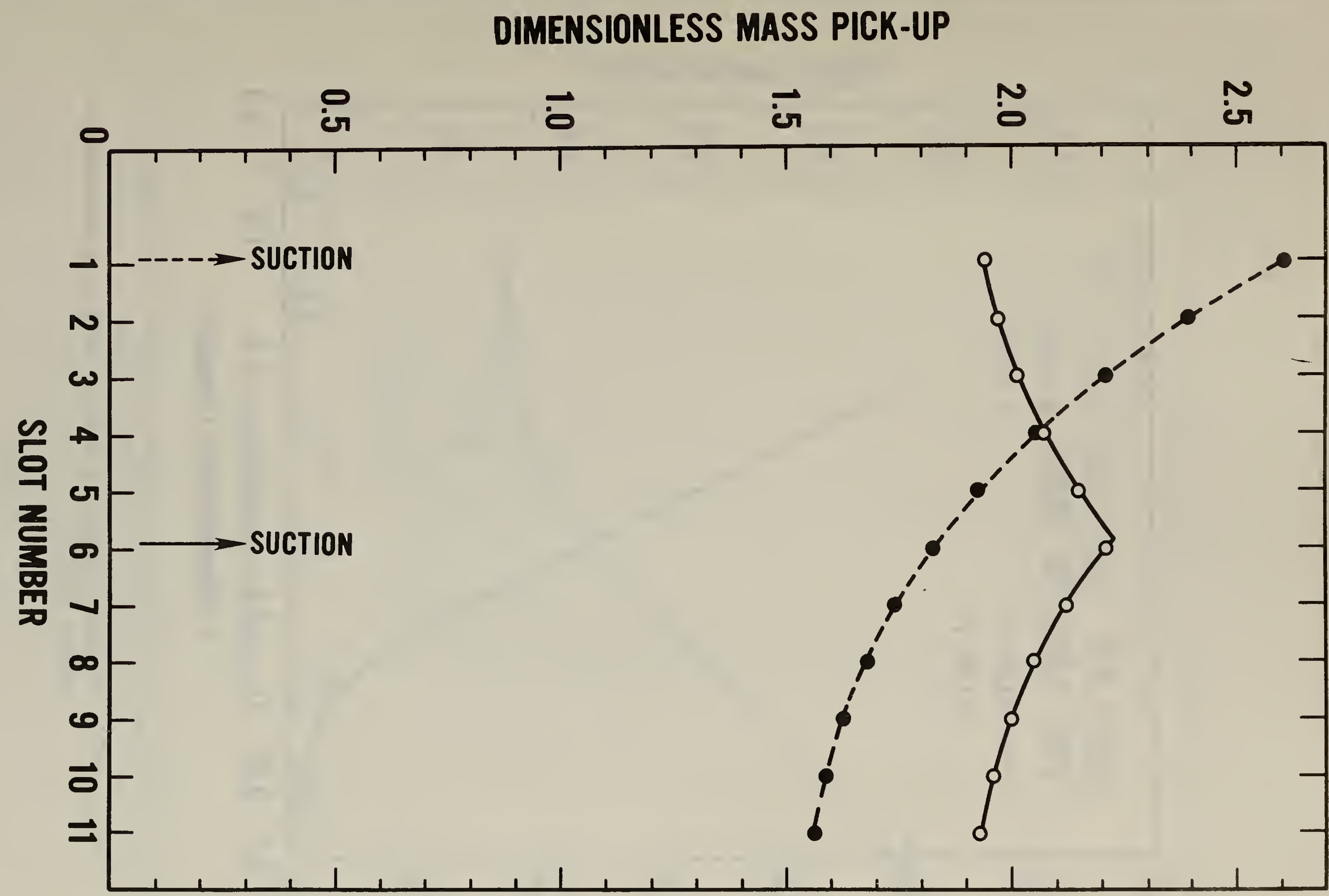

Figure 16. Dimensionless mass pick-up as a function of slot number for a hold containing 11 slots (10 stacks of containers) for two forced ventilation suction locations: solid line, suction on hold centerline; dotted line, suction at the out-board corner of the hold

Figure 17. Dimensionless pressure as a function of dimensionless height (double precision calculation) stable stratification 0.1°C over height of hold

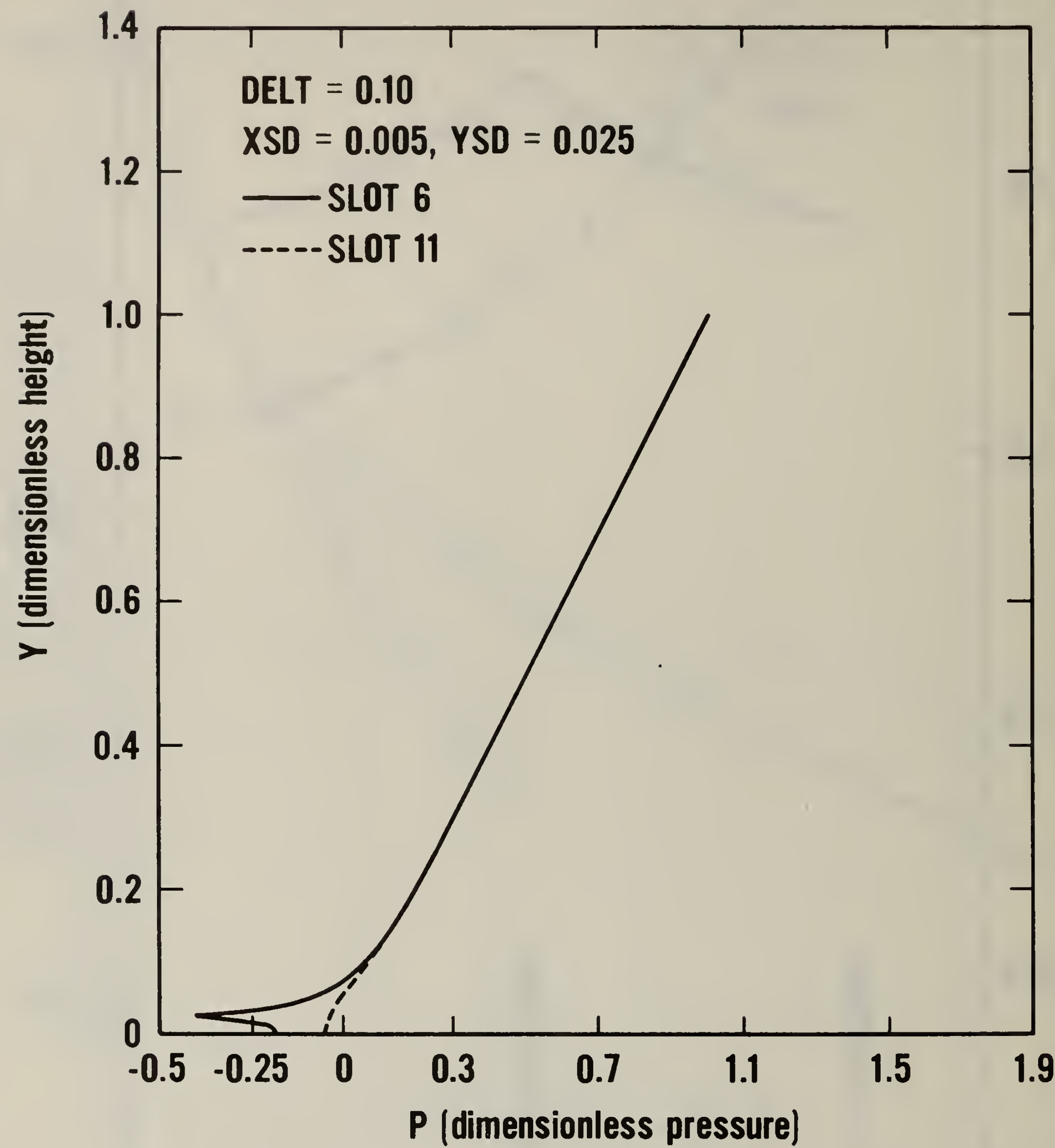

Figure 17a. Physical height of suction 0.05 m, dimensionless height 0.025

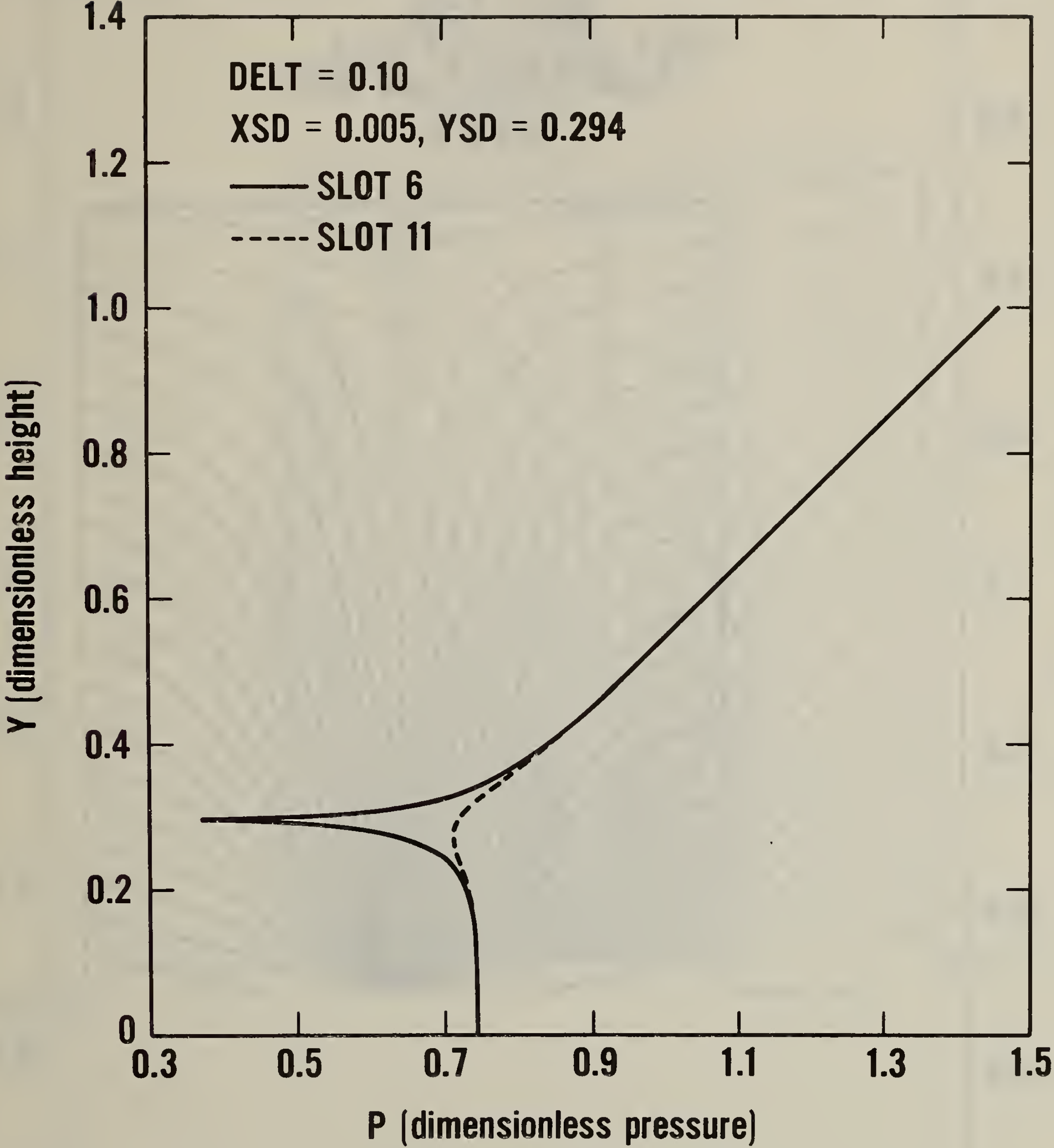

Figure 17b. Physical height of suction 0.60 m, dimensionless height 0.294

Figure 18. Slot bottom boundary layer streamlines corresponding to the pressures shown in figure 17a

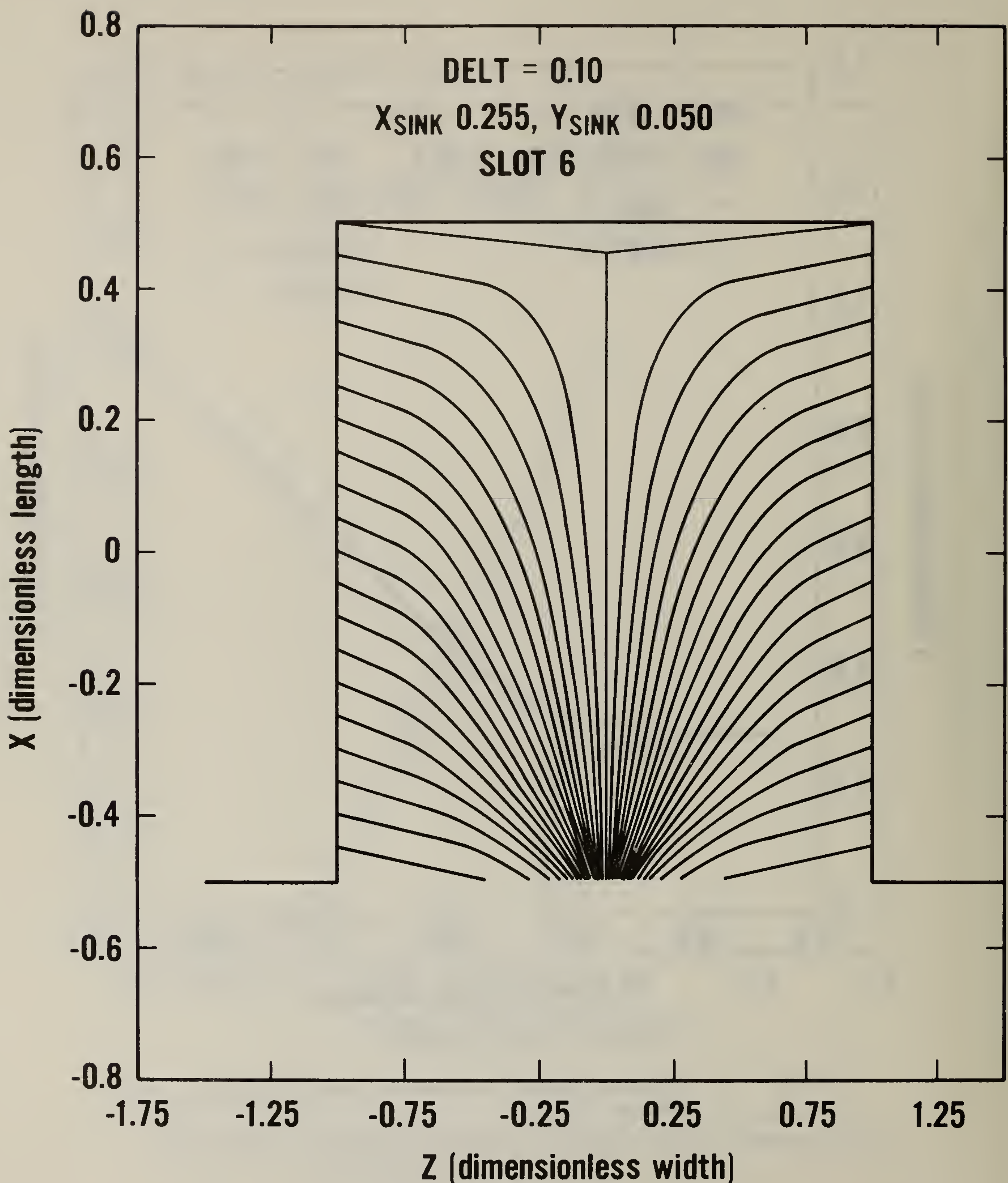

Figure 18a. Streamlines for slot at center (nearest suction)

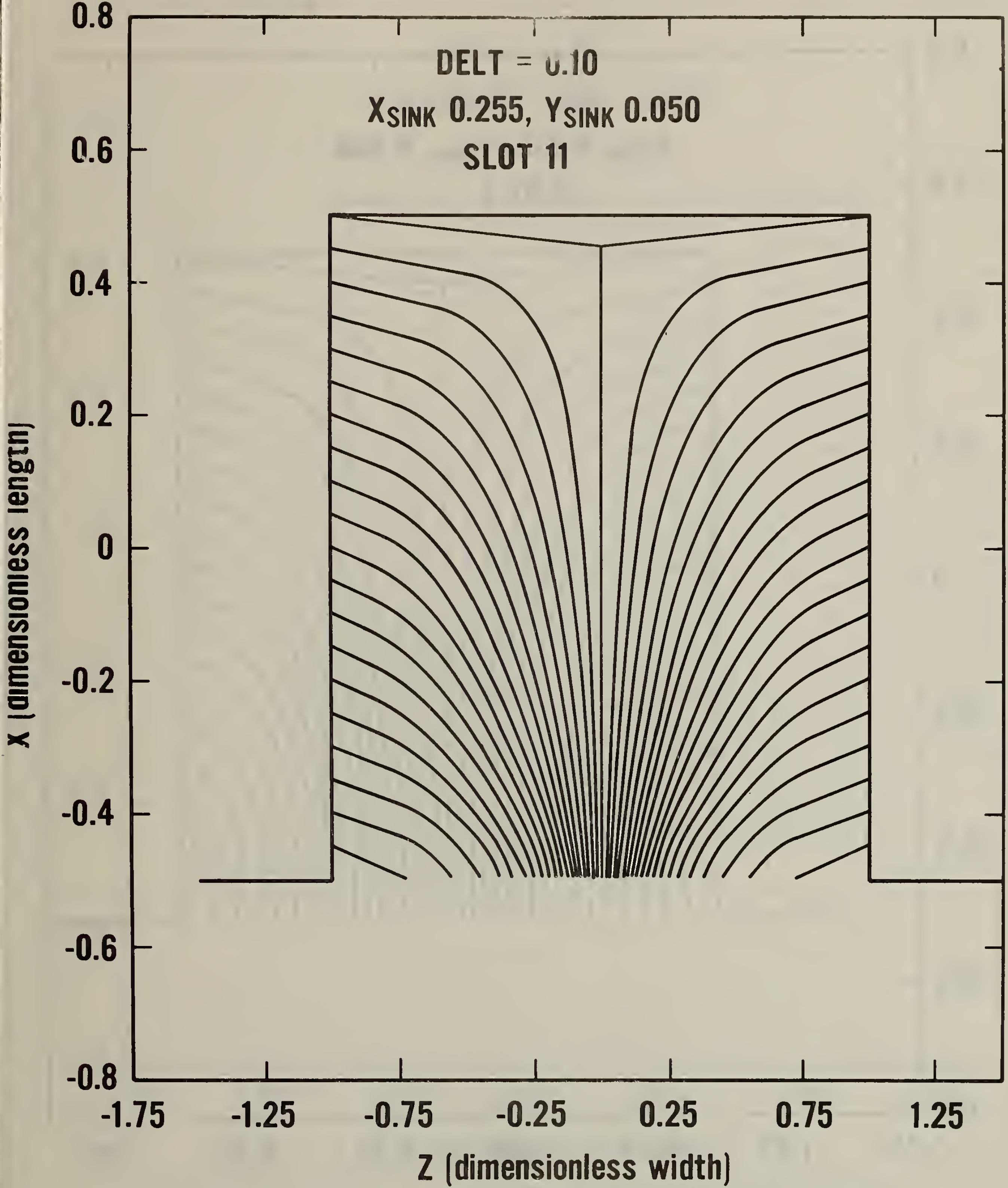

Figure 18b. Streamlines for slot at hold side (furthest from suction)

Figure 19. Slot bottom boundary layer steamlines corresponding to the pressures shown in figure 17b

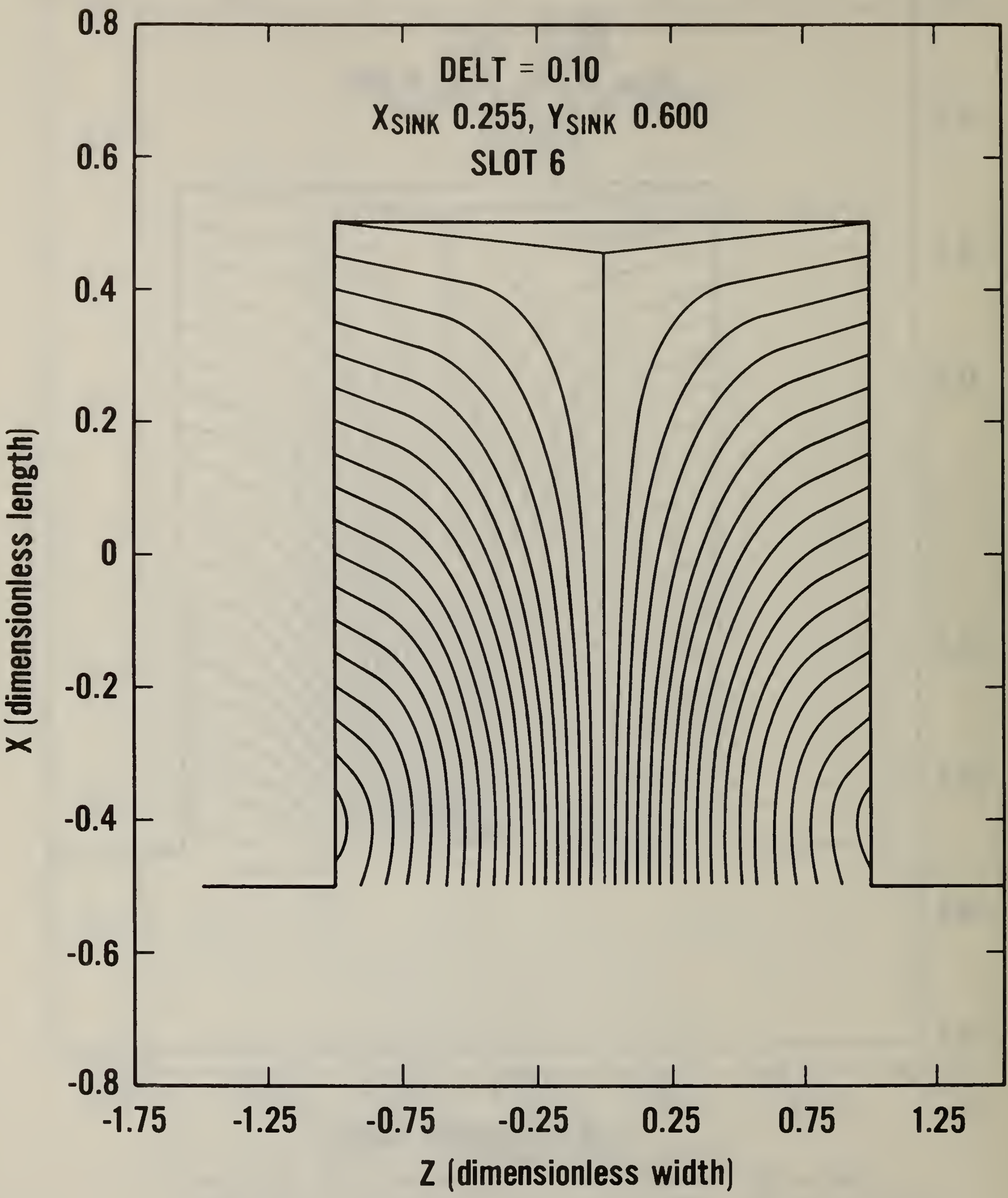

Figure 19a. Streamlines for slot at centerline (nearest suction)

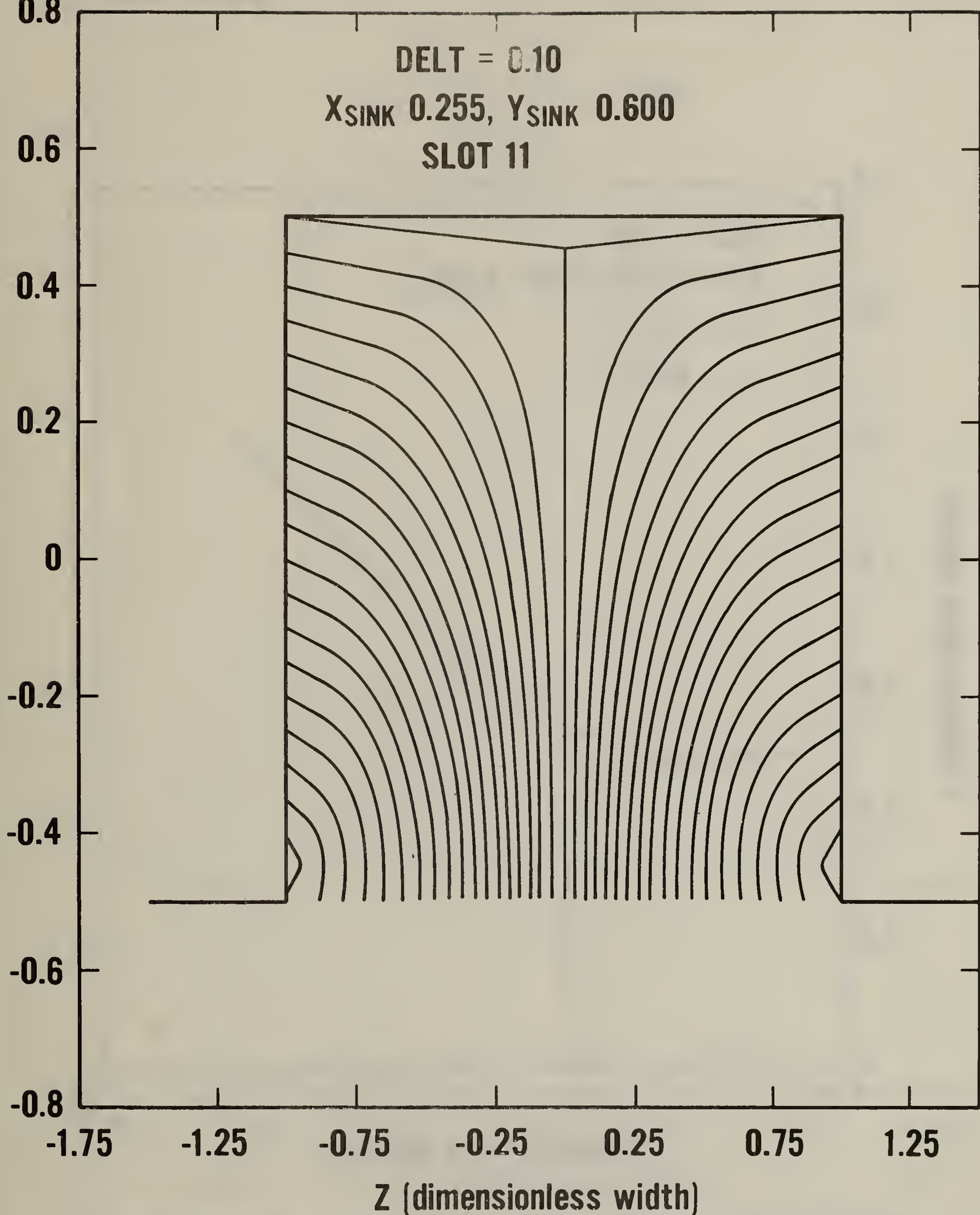

Figure 19b. Streamlines for slot at hold side (furthest from suction)

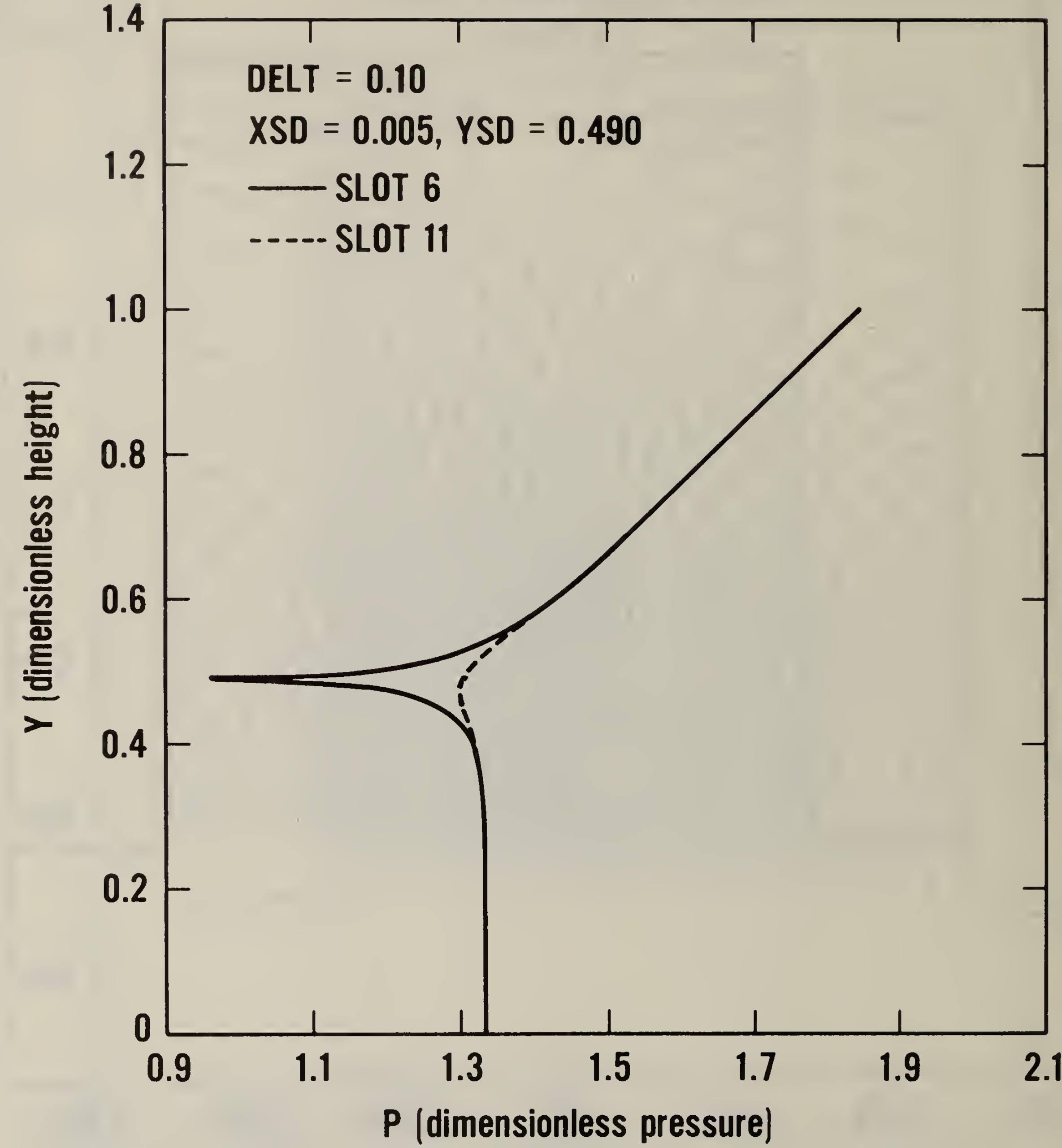

Figure 20a. Dimensionless pressure as a function of dimensionless height (double precision calculation, compare with figure 14). Suction 1 m above hold bottom

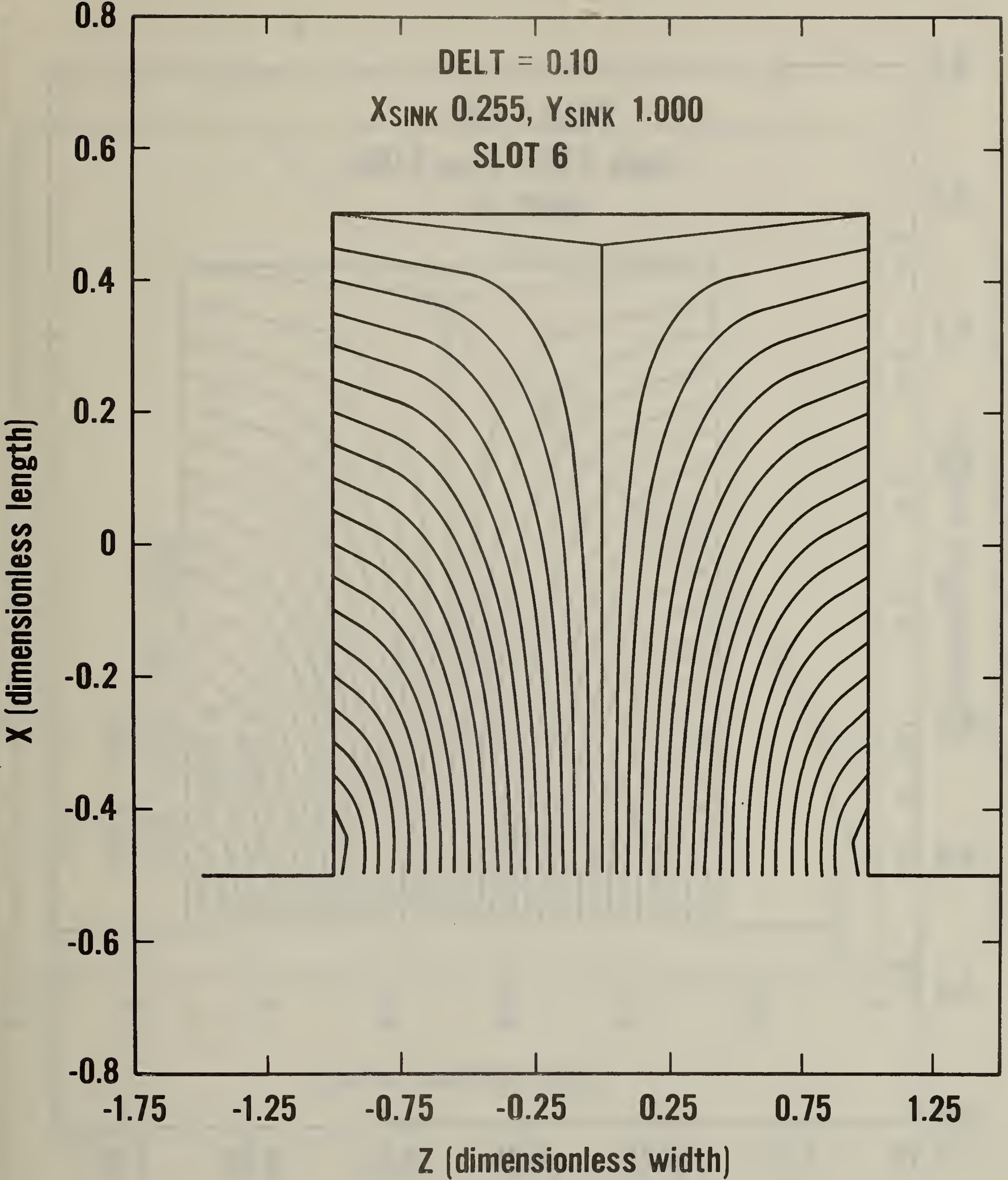

Figure 20b. Slot bottom boundary layer streamlines corresponding to the pressure shown in figure 20a. Centerline slot (nearest suction)

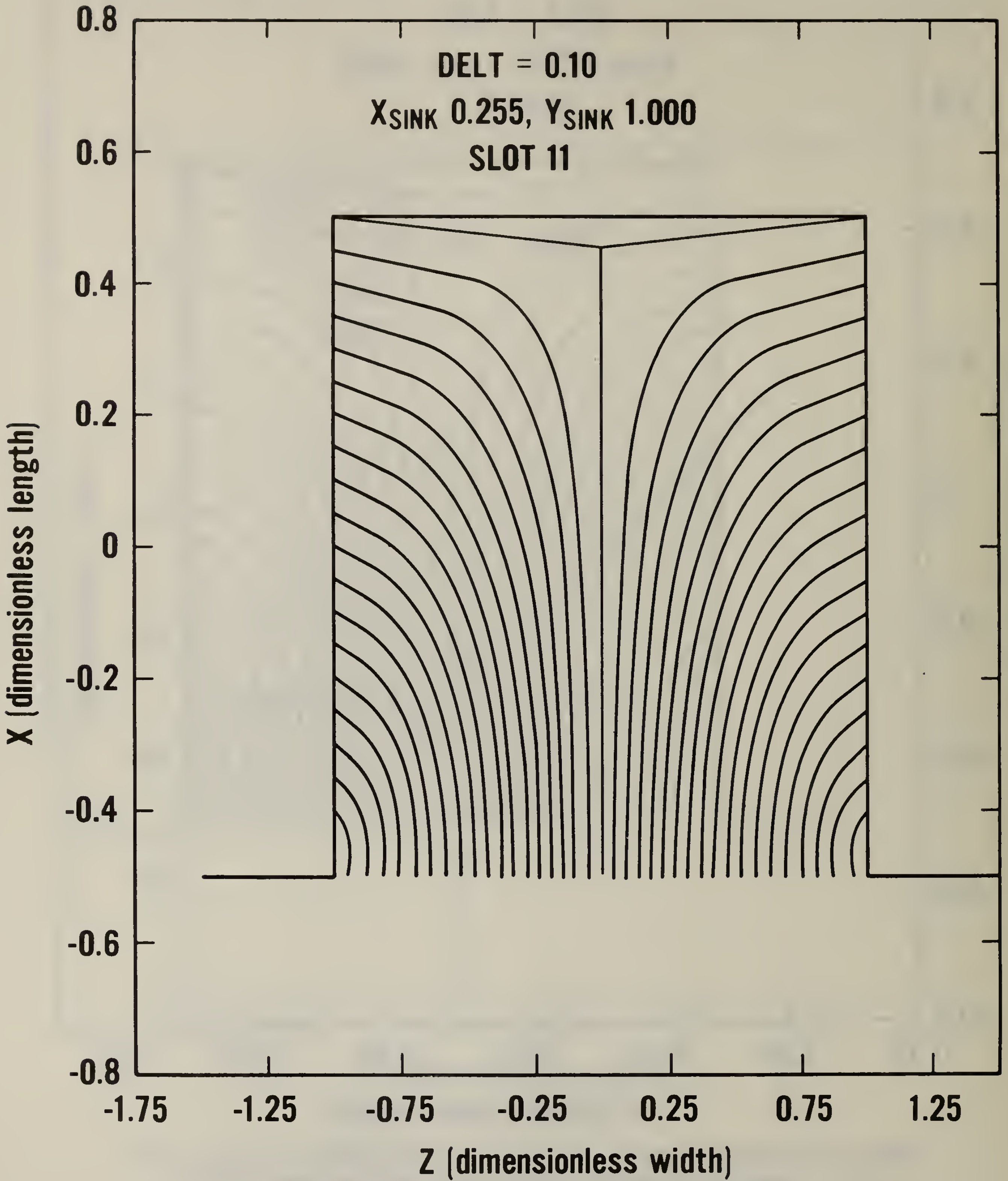

Figure 20c. Slot bottom boundary layer streamlines corresponding to the pressures shown in figure 20a. Side slot (furthest from suction)

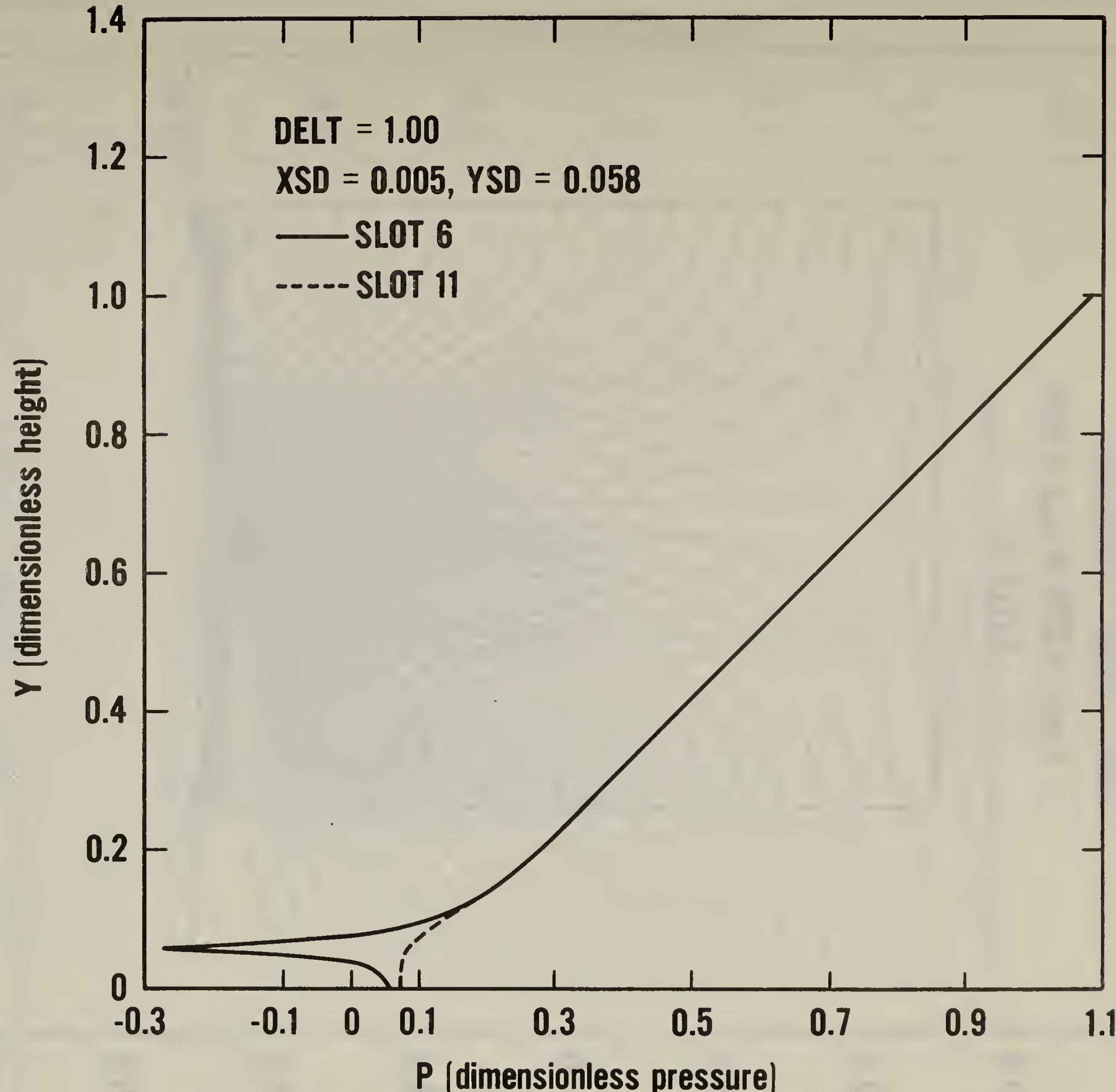

Figure 21a. Dimensionless slot pressure as a function of dimensionless height (double precision-calculation) stable stratification 1°C over height of hold (compare with figure 17)

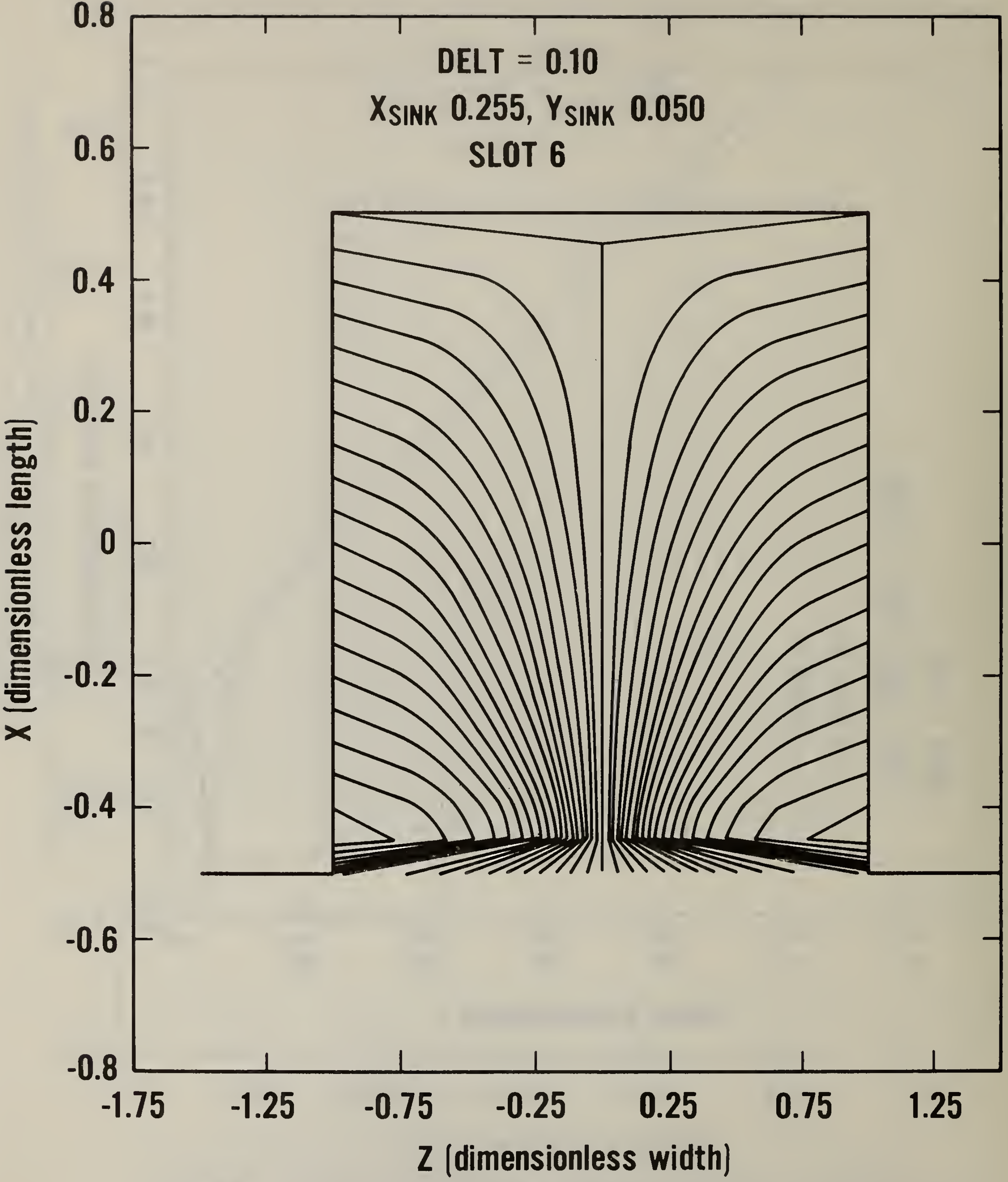

Figure 21b. Slot bottom boundary layer streamlines corresponding to the pressures shown in figure 21a. Centerline slot (nearest suction)

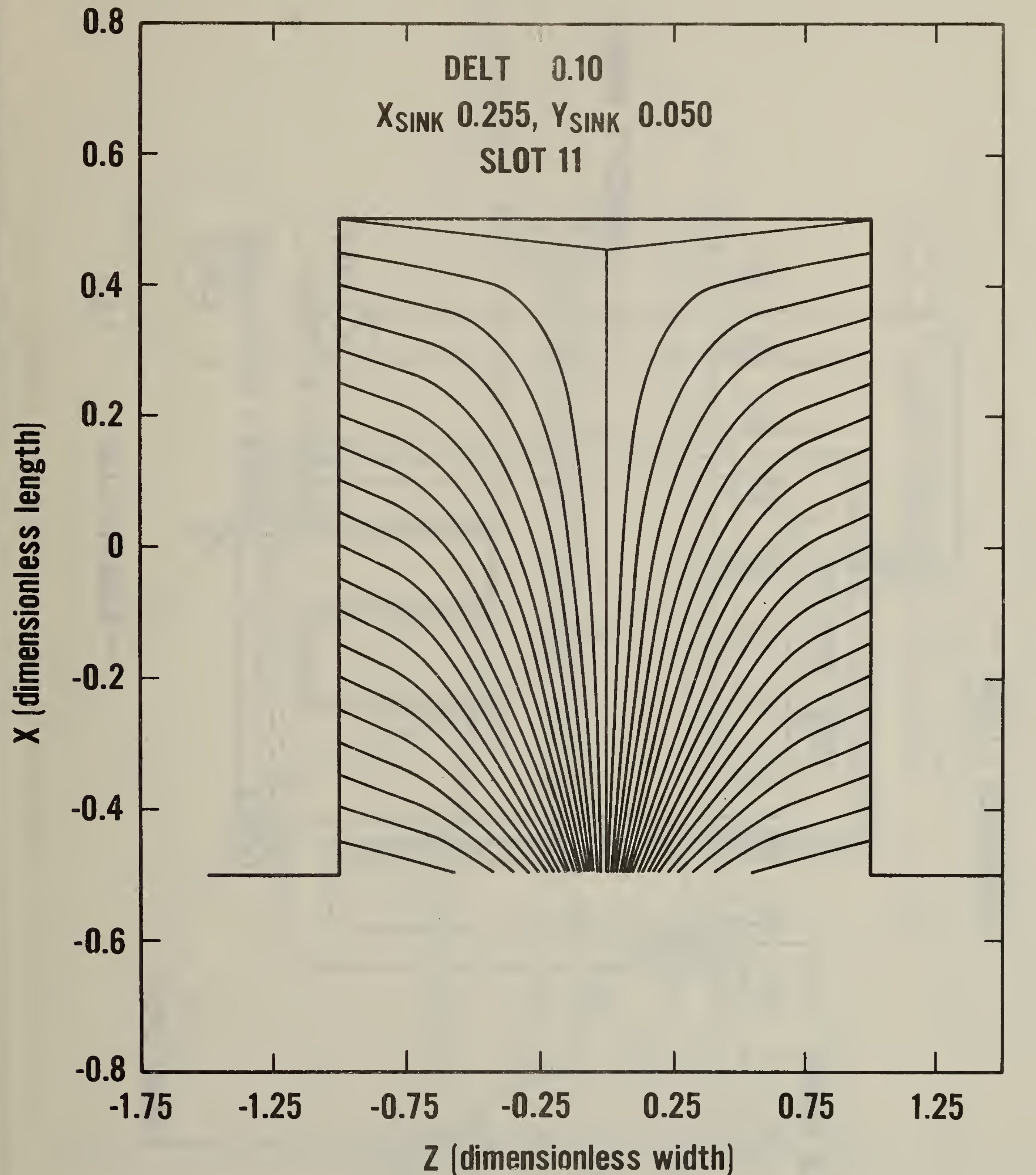

Figure 21c. Slot bottom boundary layer streamlines corresponding to the pressures shown in figure 21a. Side slot (furthest from suction)

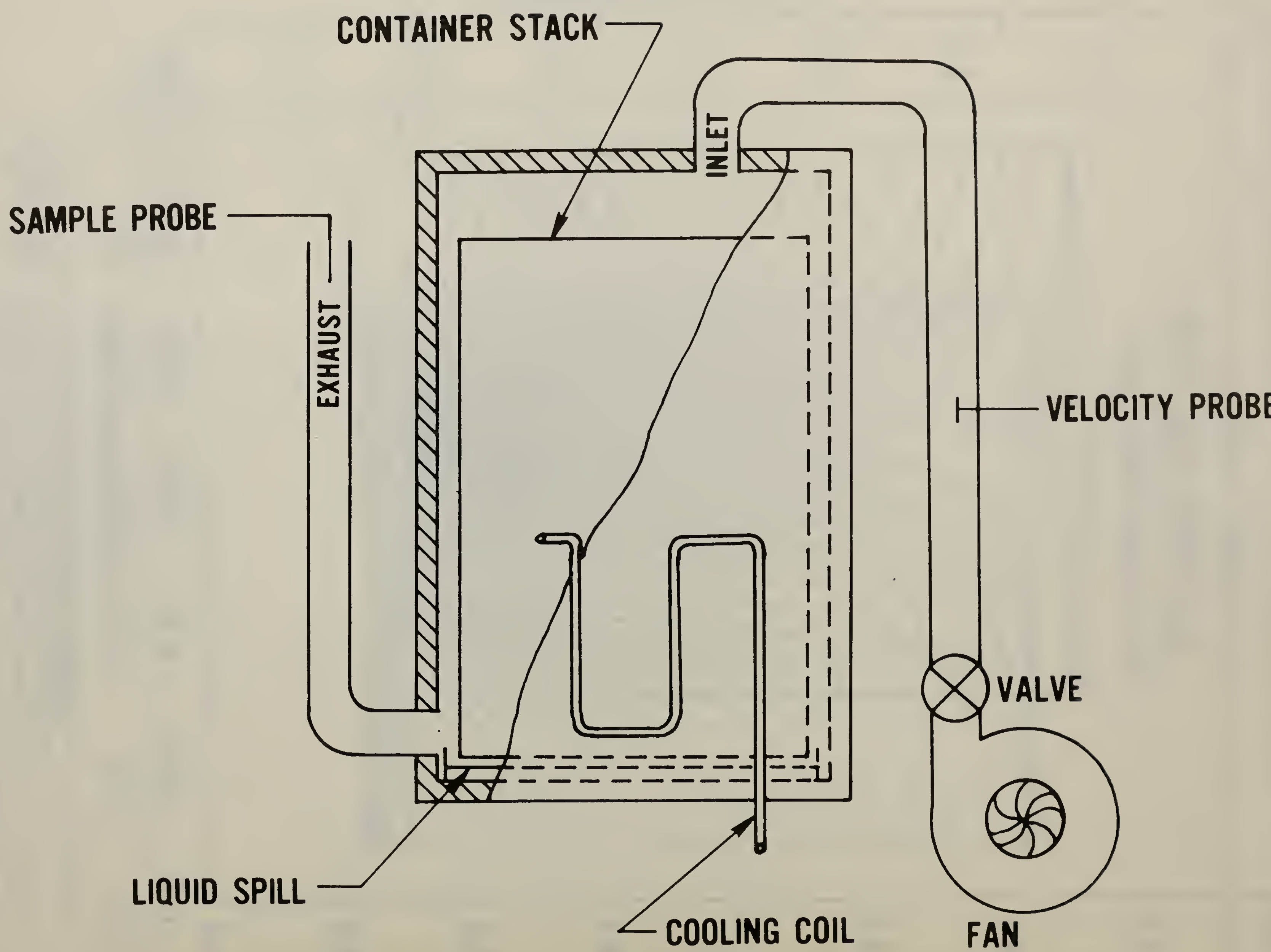

Figure 22. Simplified schematic of experimental apparatus

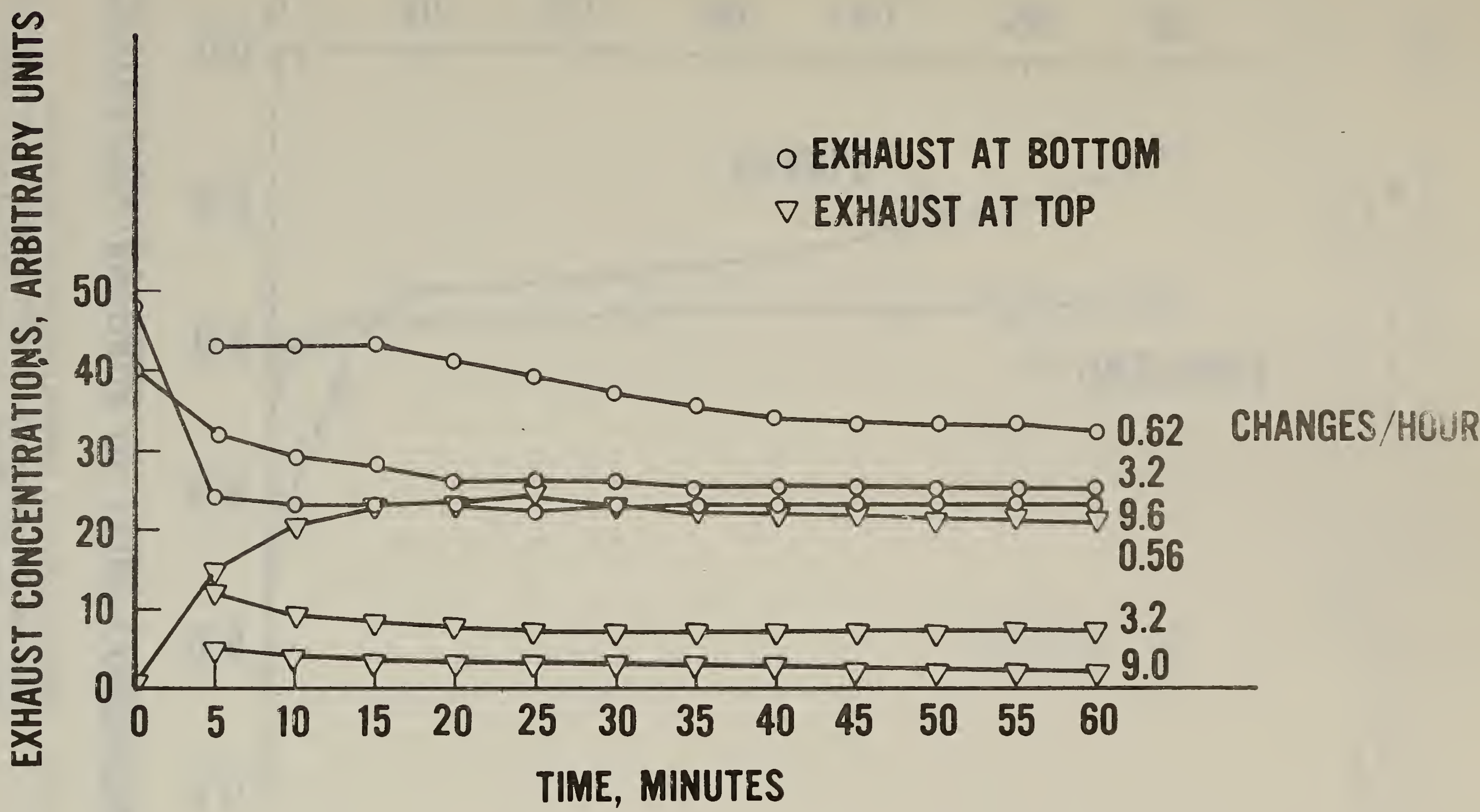

Figure 23. Concentration of combustible vapor in the exhaust duct for several ventilation rates and two suction locations

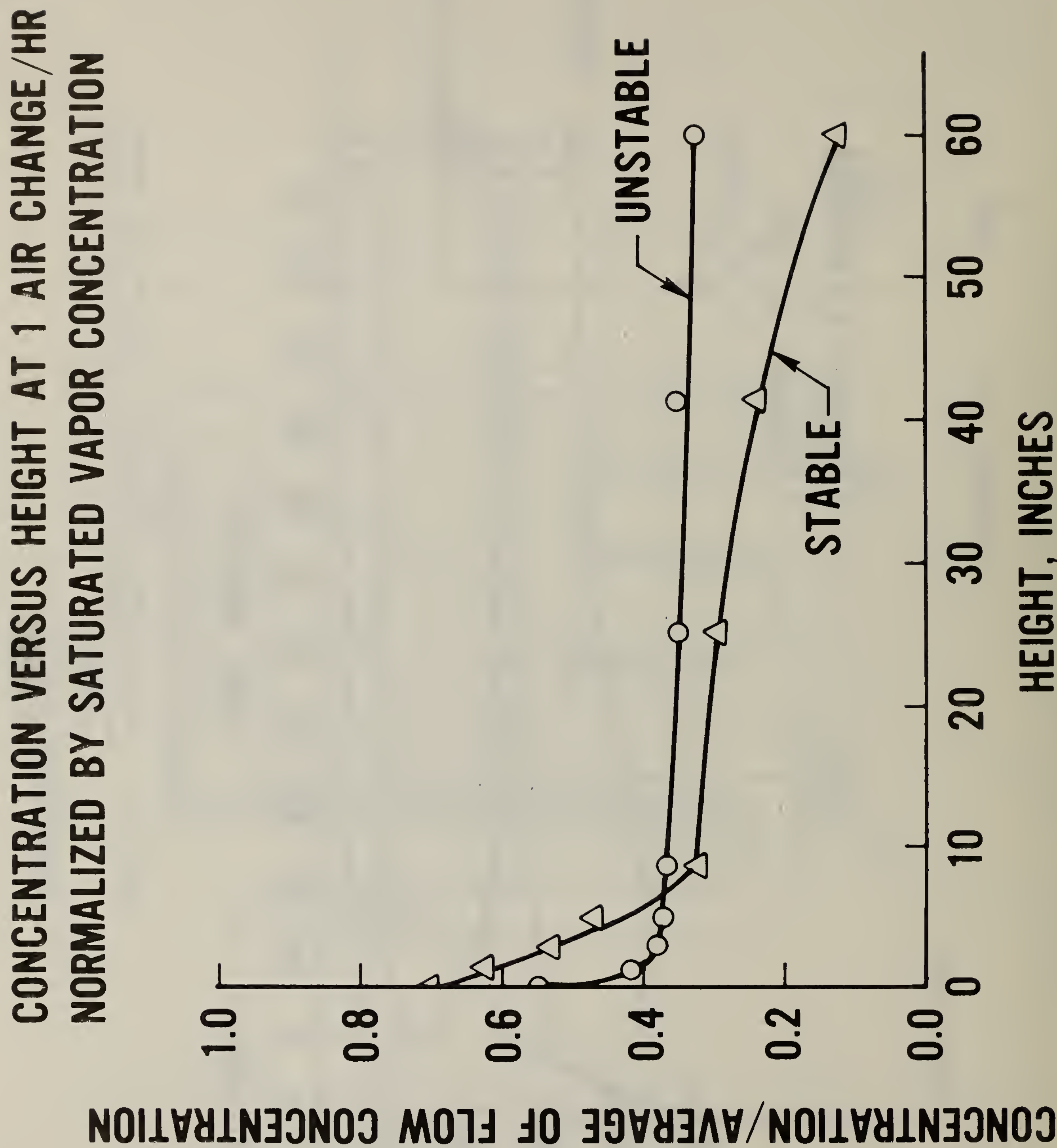

Figure 24. Concentration to combustible vapor inside the experimental enclosures versus height of the sampling point. One air change per hour forced ventilation flow, low suction

Table 1. Vertical pressure gradient effectiveness $f(\omega)$ dependence upon stratification parameter ω defined in Eq. (10) of text. $f(\omega)$ is the ratio of vertical to horizontal flow capable of being produced by a given pressure gradient.

ω	$f(\omega)$
0	1
1	.3299
2	.0878
3	.0276
4	.0117
5	.0060

Table 2. Dimensionless Mass Pick-Up
Suction Height 5 cm Mass Pick-Up

Slot #	Centerline Suction	Side Suction
1	2.01	2.72
2	2.05	2.49
3	2.12	2.29
4	2.25	2.16
5	2.37	2.00
6	2.51	1.91
7	2.34	1.82
8	2.18	1.74
9	2.12	1.74
10	2.03	1.70
11	1.95	1.66

APPENDIX 1.

Example of Input Data

```
          1
       0.10
        51.        0.8        20.
        12.        0.1        2.46
         20         11
        0.0       0.60
      2407.      1920.
          1
TEST CASE 5, HEPTANE SPILL  (C.P.)
        0.1       100.   4497.13      98.15     279.09      10.0
          1
        1.0
```

APPENDIX 2.

Output for the Input Data of Appendix 1

FIELD OF UB

Y\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
0.1000	6.87E-02	6.82E-02	6.67E-02	6.41E-02	6.04E-02	5.56E-02	4.93E-02	4.13E-02	3.12E-02	1.81E-02	-1.57E-07
0.2000	1.29E-01	1.28E-01	1.25E-01	1.20E-01	1.13E-01	1.03E-01	9.10E-02	7.55E-02	5.61E-02	3.16E-02	-1.28E-07
0.3000	1.82E-01	1.80E-01	1.76E-01	1.68E-01	1.58E-01	1.44E-01	1.26E-01	1.04E-01	7.60E-02	4.20E-02	-1.07E-07
0.4000	2.27E-01	2.25E-01	2.19E-01	2.10E-01	1.96E-01	1.78E-01	1.55E-01	1.27E-01	9.22E-02	5.03E-02	-8.97E-08
0.5000	2.66E-01	2.64E-01	2.57E-01	2.45E-01	2.29E-01	2.07E-01	1.80E-01	1.46E-01	1.06E-01	5.72E-02	-7.59E-08
0.6000	3.00E-01	2.97E-01	2.89E-01	2.76E-01	2.57E-01	2.32E-01	2.00E-01	1.62E-01	1.17E-01	6.29E-02	-6.44E-08
0.7000	3.29E-01	3.26E-01	3.17E-01	3.02E-01	2.80E-01	2.53E-01	2.18E-01	1.76E-01	1.26E-01	6.77E-02	-5.48E-08
0.8000	3.53E-01	3.50E-01	3.40E-01	3.24E-01	3.01E-01	2.71E-01	2.33E-01	1.88E-01	1.34E-01	7.18E-02	-4.66E-08
0.9000	3.75E-01	3.71E-01	3.61E-01	3.43E-01	3.18E-01	2.86E-01	2.46E-01	1.98E-01	1.41E-01	7.52E-02	-3.98E-08
1.0000	3.93E-01	3.89E-01	3.78E-01	3.59E-01	3.33E-01	2.99E-01	2.57E-01	2.06E-01	1.47E-01	7.81E-02	-3.39E-08

FIELD OF UBC

Y\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
0.0500	7.04E-01	6.99E-01	6.84E-01	6.58E-01	6.21E-01	5.72E-01	5.09E-01	4.29E-01	3.27E-01	1.93E-01	-3.86E-06

FIELD OF W = INDEFINATE Z INTEGRAL OF UB

Y\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
0.1000	0.00E+00	6.84E-03	1.36E-02	2.01E-02	2.64E-02	3.21E-02	3.74E-02	4.19E-02	4.55E-02	4.80E-02	4.89E-02
0.2000	0.00E+00	1.29E-02	2.55E-02	3.78E-02	4.95E-02	6.03E-02	7.00E-02	7.83E-02	8.49E-02	8.93E-02	9.08E-02
0.3000	0.00E+00	1.81E-02	3.59E-02	5.31E-02	6.94E-02	8.45E-02	9.80E-02	1.09E-01	1.18E-01	1.24E-01	1.26E-01
0.4000	0.00E+00	2.26E-02	4.48E-02	6.63E-02	8.66E-02	1.05E-01	1.22E-01	1.36E-01	1.47E-01	1.54E-01	1.57E-01
0.5000	0.00E+00	2.65E-02	5.25E-02	7.76E-02	1.01E-01	1.23E-01	1.42E-01	1.59E-01	1.71E-01	1.79E-01	1.82E-01
0.6000	0.00E+00	2.98E-02	5.91E-02	8.74E-02	1.14E-01	1.38E-01	1.60E-01	1.78E-01	1.92E-01	2.01E-01	2.04E-01
0.7000	0.00E+00	3.27E-02	6.48E-02	9.57E-02	1.25E-01	1.51E-01	1.75E-01	1.95E-01	2.10E-01	2.20E-01	2.23E-01
0.8000	0.00E+00	3.52E-02	6.97E-02	1.03E-01	1.34E-01	1.63E-01	1.88E-01	2.09E-01	2.25E-01	2.35E-01	2.39E-01
0.9000	0.00E+00	3.73E-02	7.39E-02	1.09E-01	1.42E-01	1.72E-01	1.99E-01	2.21E-01	2.38E-01	2.49E-01	2.53E-01
1.0000	0.00E+00	3.91E-02	7.74E-02	1.14E-01	1.49E-01	1.80E-01	2.08E-01	2.31E-01	2.49E-01	2.60E-01	2.64E-01

FIELD OF WO = INDEFINATE Z INTEGRAL OF UBO

Y\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
0.0500	0.00E+00	7.01E-02	1.39E-01	2.06E-01	2.70E-01	3.30E-01	3.84E-01	4.31E-01	4.69E-01	4.95E-01	5.04E-01

```
INPUT PARAMETERS:
  TC    =10.00      DELT = 0.100000            DEG C.
  XL    =51.00      YE   = 0.80      ZH=20.00 M
  XSLOT=12.00       YSLOT= 0.10                M

 11 INTERCONTAINER SLOTS SPACED= 2.46 M

NUMBER OF POINTS TABULATED:
  NXSLOT= 20


SCALING PARAMETERS
  GRASH   =  9.8459E+05     OMEGA =  7.7690E+00
  SQRT(F) =  3.9993E-02

  GRSLOT  =  1.9230E+03     OMSLOT=  9.7112E-01
  SQRT(FS)=  7.9776E-01


THE MODEL ASSUMES THE SLOTS ARE WIDELY SPACED
COMPARED TO THE VOID WIDTH (AFTER SCALING).
INTERCONTAINER SLOT SPACING = 2.46 M

MAIN VOID WIDTH            = 0.80 M

SCALED SPACING/VOID WIDTH  =  1.22979E-01


SUCTION MOVED TO AVOID SLOT-VOID INTERSECTION
XSINK =  0.00E+00TO XSINK =  2.55E-01


MAIN SUCTION
  XSINK = 0.2550 M     YSINK = 0.6000 M
```

INTERCONTAINER SLOT VELOCITY - U

X\LOC=	1.23E+01	9.84E+00	7.38E+00	4.92E+00	2.46E+00	0.00E+00	-2.46E+00	-4.92E+00	-7.38E+00	-9.84E+00	-1.23E+01
-6.0000	8.614E-01	8.542E-01	8.427E-01	8.271E-01	8.079E-01	7.949E-01	8.132E-01	8.328E-01	8.486E-01	8.602E-01	8.676E-01
-5.4000	8.676E-01	8.597E-01	8.483E-01	8.334E-01	8.153E-01	8.032E-01	8.200E-01	8.382E-01	8.532E-01	8.646E-01	8.724E-01
-4.8000	8.590E-01	8.525E-01	8.434E-01	8.316E-01	8.174E-01	8.079E-01	8.210E-01	8.351E-01	8.468E-01	8.553E-01	8.622E-01
-4.2000	8.334E-01	8.290E-01	8.229E-01	8.151E-01	8.056E-01	7.992E-01	8.079E-01	8.173E-01	8.250E-01	8.309E-01	8.352E-01
-3.6000	7.942E-01	7.917E-01	7.882E-01	7.838E-01	7.784E-01	7.748E-01	7.796E-01	7.849E-01	7.892E-01	7.926E-01	7.950E-01
-3.0000	7.460E-01	7.448E-01	7.433E-01	7.413E-01	7.389E-01	7.373E-01	7.394E-01	7.418E-01	7.436E-01	7.451E-01	7.462E-01
-2.4000	6.928E-01	6.926E-01	6.923E-01	6.919E-01	6.913E-01	6.911E-01	6.914E-01	6.919E-01	6.922E-01	6.925E-01	6.927E-01
-1.8000	6.376E-01	6.378E-01	6.383E-01	6.388E-01	6.394E-01	6.399E-01	6.392E-01	6.385E-01	6.380E-01	6.375E-01	6.373E-01
-1.2000	5.821E-01	5.826E-01	5.834E-01	5.844E-01	5.856E-01	5.866E-01	5.852E-01	5.840E-01	5.830E-01	5.822E-01	5.816E-01
-0.6000	5.273E-01	5.279E-01	5.289E-01	5.301E-01	5.316E-01	5.327E-01	5.312E-01	5.297E-01	5.284E-01	5.274E-01	5.268E-01
0.0000	4.737E-01	4.744E-01	4.754E-01	4.767E-01	4.782E-01	4.794E-01	4.775E-01	4.763E-01	4.750E-01	4.740E-01	4.733E-01
0.6000	4.217E-01	4.224E-01	4.233E-01	4.246E-01	4.261E-01	4.272E-01	4.256E-01	4.241E-01	4.229E-01	4.219E-01	4.213E-01
1.2000	3.712E-01	3.718E-01	3.727E-01	3.738E-01	3.752E-01	3.763E-01	3.748E-01	3.735E-01	3.723E-01	3.714E-01	3.708E-01
1.8000	3.222E-01	3.227E-01	3.235E-01	3.245E-01	3.257E-01	3.267E-01	3.254E-01	3.242E-01	3.232E-01	3.224E-01	3.218E-01
2.4000	2.744E-01	2.749E-01	2.756E-01	2.765E-01	2.775E-01	2.783E-01	2.772E-01	2.762E-01	2.753E-01	2.746E-01	2.741E-01
3.0000	2.279E-01	2.283E-01	2.288E-01	2.296E-01	2.304E-01	2.311E-01	2.302E-01	2.293E-01	2.286E-01	2.280E-01	2.276E-01
3.6000	1.823E-01	1.826E-01	1.830E-01	1.836E-01	1.843E-01	1.849E-01	1.841E-01	1.834E-01	1.829E-01	1.824E-01	1.821E-01
4.2000	1.375E-01	1.377E-01	1.380E-01	1.385E-01	1.390E-01	1.394E-01	1.388E-01	1.383E-01	1.379E-01	1.376E-01	1.373E-01
4.8000	9.322E-02	9.338E-02	9.361E-02	9.389E-02	9.423E-02	9.450E-02	9.414E-02	9.380E-02	9.351E-02	9.329E-02	9.313E-02
5.4000	4.937E-02	4.945E-02	4.956E-02	4.971E-02	4.988E-02	5.001E-02	4.983E-02	4.966E-02	4.952E-02	4.940E-02	4.933E-02
6.0000	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03	5.719E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X = 12.30

X\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.0000	0.000E+00	6.041E-02	1.200E-01	1.778E-01	2.329E-01	2.843E-01	3.308E-01	3.712E-01	4.038E-01	4.261E-01	4.345E-01
-5.4000	0.000E+00	6.085E-02	1.208E-01	1.790E-01	2.345E-01	2.863E-01	3.332E-01	3.739E-01	4.067E-01	4.292E-01	4.376E-01
-4.8000	0.000E+00	6.025E-02	1.196E-01	1.773E-01	2.322E-01	2.835E-01	3.299E-01	3.702E-01	4.026E-01	4.250E-01	4.333E-01
-4.2000	0.000E+00	5.845E-02	1.161E-01	1.720E-01	2.253E-01	2.750E-01	3.201E-01	3.592E-01	3.907E-01	4.123E-01	4.204E-01
-3.6000	0.000E+00	5.570E-02	1.106E-01	1.639E-01	2.147E-01	2.621E-01	3.050E-01	3.423E-01	3.723E-01	3.929E-01	4.006E-01
-3.0000	0.000E+00	5.232E-02	1.039E-01	1.539E-01	2.017E-01	2.462E-01	2.865E-01	3.215E-01	3.497E-01	3.691E-01	3.763E-01
-2.4000	0.000E+00	4.859E-02	9.649E-02	1.430E-01	1.873E-01	2.287E-01	2.661E-01	2.986E-01	3.248E-01	3.428E-01	3.495E-01
-1.8000	0.000E+00	4.472E-02	8.880E-02	1.316E-01	1.724E-01	2.104E-01	2.449E-01	2.748E-01	2.989E-01	3.154E-01	3.216E-01
-1.2000	0.000E+00	4.082E-02	8.106E-02	1.201E-01	1.574E-01	1.921E-01	2.236E-01	2.508E-01	2.728E-01	2.880E-01	2.936E-01
-0.6000	0.000E+00	3.698E-02	7.343E-02	1.088E-01	1.425E-01	1.740E-01	2.025E-01	2.272E-01	2.471E-01	2.609E-01	2.659E-01
0.0000	0.000E+00	3.323E-02	6.599E-02	9.776E-02	1.281E-01	1.563E-01	1.819E-01	2.042E-01	2.221E-01	2.344E-01	2.389E-01
0.6000	0.000E+00	2.958E-02	5.873E-02	8.702E-02	1.140E-01	1.392E-01	1.620E-01	1.817E-01	1.977E-01	2.086E-01	2.127E-01
1.2000	0.000E+00	2.604E-02	5.170E-02	7.660E-02	1.004E-01	1.225E-01	1.426E-01	1.600E-01	1.740E-01	1.836E-01	1.872E-01
1.8000	0.000E+00	2.260E-02	4.487E-02	6.648E-02	8.709E-02	1.063E-01	1.237E-01	1.388E-01	1.510E-01	1.594E-01	1.625E-01
2.4000	0.000E+00	1.925E-02	3.822E-02	5.664E-02	7.419E-02	9.057E-02	1.054E-01	1.183E-01	1.286E-01	1.358E-01	1.384E-01
3.0000	0.000E+00	1.598E-02	3.174E-02	4.703E-02	6.160E-02	7.520E-02	8.752E-02	9.821E-02	1.068E-01	1.127E-01	1.149E-01
3.6000	0.000E+00	1.278E-02	2.539E-02	3.762E-02	4.928E-02	6.016E-02	7.001E-02	7.856E-02	8.544E-02	9.018E-02	9.194E-02
4.2000	0.000E+00	9.641E-03	1.914E-02	2.837E-02	3.716E-02	4.536E-02	5.280E-02	5.924E-02	6.443E-02	6.801E-02	6.933E-02

4.8000	0.000E+00	6.538E-03	1.298E-02	1.924E-02	2.520E-02	3.077E-02	3.580E-02	4.018E-02	4.370E-02	4.612E-02	4.702E-02
5.4000	0.000E+00	3.463E-03	6.876E-03	1.019E-02	1.335E-02	1.629E-02	1.896E-02	2.128E-02	2.314E-02	2.443E-02	2.490E-02
6.0000	0.000E+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X = 9.84

X\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.0000	0.000E+00	5.991E-02	1.190E-01	1.763E-01	2.309E-01	2.819E-01	3.281E-01	3.681E-01	4.004E-01	4.226E-01	4.308E-01
-5.4000	0.000E+00	6.030E-02	1.197E-01	1.774E-01	2.324E-01	2.837E-01	3.302E-01	3.705E-01	4.030E-01	4.253E-01	4.336E-01
-4.8000	0.000E+00	5.979E-02	1.187E-01	1.759E-01	2.305E-01	2.813E-01	3.274E-01	3.674E-01	3.996E-01	4.218E-01	4.300E-01
-4.2000	0.000E+00	5.814E-02	1.155E-01	1.711E-01	2.241E-01	2.736E-01	3.184E-01	3.573E-01	3.886E-01	4.101E-01	4.181E-01
-3.6000	0.000E+00	5.552E-02	1.103E-01	1.634E-01	2.140E-01	2.613E-01	3.041E-01	3.412E-01	3.711E-01	3.917E-01	3.993E-01
-3.0000	0.000E+00	5.224E-02	1.037E-01	1.537E-01	2.014E-01	2.458E-01	2.861E-01	3.210E-01	3.491E-01	3.685E-01	3.757E-01
-2.4000	0.000E+00	4.858E-02	9.645E-02	1.429E-01	1.872E-01	2.286E-01	2.660E-01	2.985E-01	3.246E-01	3.426E-01	3.493E-01
-1.8000	0.000E+00	4.474E-02	8.883E-02	1.316E-01	1.724E-01	2.105E-01	2.450E-01	2.749E-01	2.990E-01	3.156E-01	3.217E-01
-1.2000	0.000E+00	4.086E-02	8.114E-02	1.202E-01	1.575E-01	1.923E-01	2.238E-01	2.511E-01	2.731E-01	2.882E-01	2.938E-01
-0.6000	0.000E+00	3.703E-02	7.352E-02	1.089E-01	1.427E-01	1.742E-01	2.028E-01	2.275E-01	2.475E-01	2.612E-01	2.663E-01
0.0000	0.000E+00	3.327E-02	6.607E-02	9.790E-02	1.283E-01	1.566E-01	1.822E-01	2.045E-01	2.224E-01	2.347E-01	2.393E-01
0.6000	0.000E+00	2.962E-02	5.882E-02	8.716E-02	1.142E-01	1.394E-01	1.622E-01	1.820E-01	1.980E-01	2.090E-01	2.130E-01
1.2000	0.000E+00	2.608E-02	5.178E-02	7.673E-02	1.005E-01	1.227E-01	1.428E-01	1.602E-01	1.743E-01	1.839E-01	1.875E-01
1.8000	0.000E+00	2.263E-02	4.494E-02	6.660E-02	8.724E-02	1.065E-01	1.239E-01	1.391E-01	1.513E-01	1.597E-01	1.628E-01
2.4000	0.000E+00	1.928E-02	3.829E-02	5.673E-02	7.432E-02	9.073E-02	1.056E-01	1.185E-01	1.289E-01	1.360E-01	1.387E-01
3.0000	0.000E+00	1.601E-02	3.179E-02	4.711E-02	6.171E-02	7.533E-02	8.767E-02	9.838E-02	1.070E-01	1.129E-01	1.151E-01
3.6000	0.000E+00	1.281E-02	2.543E-02	3.768E-02	4.936E-02	6.026E-02	7.013E-02	7.869E-02	8.559E-02	9.033E-02	9.210E-02
4.2000	0.000E+00	9.658E-03	1.918E-02	2.842E-02	3.722E-02	4.544E-02	5.289E-02	5.934E-02	6.454E-02	6.812E-02	6.945E-02
4.8000	0.000E+00	6.549E-03	1.301E-02	1.927E-02	2.524E-02	3.082E-02	3.587E-02	4.024E-02	4.377E-02	4.620E-02	4.710E-02
5.4000	0.000E+00	3.468E-03	6.887E-03	1.021E-02	1.337E-02	1.632E-02	1.899E-02	2.131E-02	2.318E-02	2.447E-02	2.494E-02
6.0000	0.000E+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X = 7.38

X\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.0000	0.000E+00	5.911E-02	1.174E-01	1.739E-01	2.278E-01	2.781E-01	3.237E-01	3.632E-01	3.950E-01	4.169E-01	4.250E-01
-5.4000	0.000E+00	5.950E-02	1.181E-01	1.751E-01	2.293E-01	2.800E-01	3.258E-01	3.656E-01	3.976E-01	4.197E-01	4.279E-01
-4.8000	0.000E+00	5.915E-02	1.175E-01	1.740E-01	2.280E-01	2.783E-01	3.239E-01	3.635E-01	3.953E-01	4.172E-01	4.254E-01
-4.2000	0.000E+00	5.772E-02	1.146E-01	1.698E-01	2.225E-01	2.716E-01	3.161E-01	3.546E-01	3.857E-01	4.071E-01	4.151E-01
-3.6000	0.000E+00	5.528E-02	1.098E-01	1.627E-01	2.131E-01	2.601E-01	3.027E-01	3.397E-01	3.695E-01	3.899E-01	3.976E-01
-3.0000	0.000E+00	5.213E-02	1.035E-01	1.534E-01	2.009E-01	2.453E-01	2.855E-01	3.203E-01	3.484E-01	3.677E-01	3.749E-01
-2.4000	0.000E+00	4.855E-02	9.641E-02	1.429E-01	1.871E-01	2.285E-01	2.659E-01	2.983E-01	3.245E-01	3.425E-01	3.492E-01
-1.8000	0.000E+00	4.477E-02	8.889E-02	1.317E-01	1.725E-01	2.106E-01	2.451E-01	2.751E-01	2.992E-01	3.158E-01	3.219E-01
-1.2000	0.000E+00	4.092E-02	8.125E-02	1.204E-01	1.577E-01	1.925E-01	2.241E-01	2.514E-01	2.735E-01	2.886E-01	2.942E-01
-0.6000	0.000E+00	3.709E-02	7.366E-02	1.091E-01	1.430E-01	1.745E-01	2.031E-01	2.279E-01	2.479E-01	2.616E-01	2.668E-01
0.0000	0.000E+00	3.334E-02	6.621E-02	9.811E-02	1.285E-01	1.569E-01	1.826E-01	2.049E-01	2.228E-01	2.352E-01	2.398E-01
0.6000	0.000E+00	2.969E-02	5.896E-02	8.736E-02	1.144E-01	1.397E-01	1.626E-01	1.824E-01	1.984E-01	2.094E-01	2.135E-01
1.2000	0.000E+00	2.614E-02	5.191E-02	7.691E-02	1.008E-01	1.230E-01	1.431E-01	1.606E-01	1.747E-01	1.844E-01	1.880E-01
1.8000	0.000E+00	2.269E-02	4.505E-02	6.676E-02	8.746E-02	1.068E-01	1.242E-01	1.394E-01	1.516E-01	1.600E-01	1.632E-01
2.4000	0.000E+00	1.933E-02	3.838E-02	5.687E-02	7.451E-02	9.095E-02	1.059E-01	1.188E-01	1.292E-01	1.363E-01	1.390E-01
3.0000	0.000E+00	1.605E-02	3.187E-02	4.722E-02	6.186E-02	7.552E-02	8.789E-02	9.862E-02	1.073E-01	1.132E-01	1.154E-01
3.6000	0.000E+00	1.284E-02	2.549E-02	3.778E-02	4.949E-02	6.041E-02	7.030E-02	7.889E-02	8.580E-02	9.056E-02	9.233E-02

4.2000	0.000E+00	9.681E-03	1.922E-02	2.849E-02	3.732E-02	4.555E-02	5.302E-02	5.949E-02	6.470E-02	6.829E-02	6.962E-02
4.8000	0.000E+00	6.565E-03	1.304E-02	1.932E-02	2.531E-02	3.089E-02	3.595E-02	4.034E-02	4.388E-02	4.631E-02	4.721E-02
5.4000	0.000E+00	3.476E-03	6.903E-03	1.023E-02	1.340E-02	1.636E-02	1.904E-02	2.136E-02	2.323E-02	2.452E-02	2.500E-02
6.0000	0.000E+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X = 4.92

X\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.0000	0.000E+00	5.801E-02	1.152E-01	1.707E-01	2.236E-01	2.730E-01	3.177E-01	3.565E-01	3.877E-01	4.092E-01	4.172E-01
-5.4000	0.000E+00	5.845E-02	1.161E-01	1.720E-01	2.253E-01	2.750E-01	3.201E-01	3.592E-01	3.906E-01	4.123E-01	4.203E-01
-4.8000	0.000E+00	5.833E-02	1.158E-01	1.716E-01	2.248E-01	2.745E-01	3.194E-01	3.584E-01	3.898E-01	4.114E-01	4.195E-01
-4.2000	0.000E+00	5.717E-02	1.135E-01	1.682E-01	2.204E-01	2.690E-01	3.131E-01	3.513E-01	3.821E-01	4.032E-01	4.111E-01
-3.6000	0.000E+00	5.497E-02	1.092E-01	1.617E-01	2.119E-01	2.587E-01	3.010E-01	3.378E-01	3.674E-01	3.878E-01	3.953E-01
-3.0000	0.000E+00	5.199E-02	1.032E-01	1.530E-01	2.004E-01	2.446E-01	2.847E-01	3.195E-01	3.475E-01	3.668E-01	3.739E-01
-2.4000	0.000E+00	4.853E-02	9.636E-02	1.428E-01	1.870E-01	2.283E-01	2.657E-01	2.982E-01	3.243E-01	3.423E-01	3.490E-01
-1.8000	0.000E+00	4.480E-02	8.896E-02	1.318E-01	1.727E-01	2.108E-01	2.453E-01	2.753E-01	2.994E-01	3.160E-01	3.222E-01
-1.2000	0.000E+00	4.099E-02	8.139E-02	1.206E-01	1.580E-01	1.929E-01	2.245E-01	2.519E-01	2.739E-01	2.891E-01	2.948E-01
-0.6000	0.000E+00	3.718E-02	7.383E-02	1.094E-01	1.433E-01	1.749E-01	2.036E-01	2.285E-01	2.485E-01	2.623E-01	2.674E-01
0.0000	0.000E+00	3.343E-02	6.639E-02	9.838E-02	1.289E-01	1.573E-01	1.831E-01	2.054E-01	2.234E-01	2.358E-01	2.404E-01
0.6000	0.000E+00	2.978E-02	5.913E-02	8.762E-02	1.148E-01	1.401E-01	1.631E-01	1.830E-01	1.990E-01	2.100E-01	2.141E-01
1.2000	0.000E+00	2.622E-02	5.207E-02	7.715E-02	1.011E-01	1.234E-01	1.436E-01	1.611E-01	1.752E-01	1.850E-01	1.886E-01
1.8000	0.000E+00	2.276E-02	4.520E-02	6.697E-02	8.773E-02	1.071E-01	1.246E-01	1.399E-01	1.521E-01	1.605E-01	1.637E-01
2.4000	0.000E+00	1.939E-02	3.850E-02	5.705E-02	7.474E-02	9.124E-02	1.062E-01	1.191E-01	1.296E-01	1.368E-01	1.394E-01
3.0000	0.000E+00	1.610E-02	3.197E-02	4.737E-02	6.206E-02	7.576E-02	8.817E-02	9.893E-02	1.076E-01	1.136E-01	1.158E-01
3.6000	0.000E+00	1.288E-02	2.557E-02	3.789E-02	4.964E-02	6.060E-02	7.053E-02	7.914E-02	8.607E-02	9.085E-02	9.262E-02
4.2000	0.000E+00	9.712E-03	1.928E-02	2.857E-02	3.743E-02	4.570E-02	5.318E-02	5.967E-02	6.490E-02	6.850E-02	6.984E-02
4.8000	0.000E+00	6.585E-03	1.308E-02	1.938E-02	2.538E-02	3.099E-02	3.606E-02	4.046E-02	4.401E-02	4.645E-02	4.736E-02
5.4000	0.000E+00	3.486E-03	6.923E-03	1.026E-02	1.344E-02	1.640E-02	1.909E-02	2.142E-02	2.330E-02	2.459E-02	2.507E-02
6.0000	0.000E+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X = 2.46

X\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.0000	0.000E+00	5.666E-02	1.125E-01	1.667E-01	2.184E-01	2.666E-01	3.103E-01	3.482E-01	3.787E-01	3.997E-01	4.075E-01
-5.4000	0.000E+00	5.718E-02	1.135E-01	1.682E-01	2.204E-01	2.691E-01	3.131E-01	3.514E-01	3.822E-01	4.033E-01	4.112E-01
-4.8000	0.000E+00	5.733E-02	1.138E-01	1.687E-01	2.210E-01	2.698E-01	3.140E-01	3.523E-01	3.832E-01	4.044E-01	4.123E-01
-4.2000	0.000E+00	5.650E-02	1.122E-01	1.662E-01	2.178E-01	2.659E-01	3.094E-01	3.472E-01	3.776E-01	3.985E-01	4.063E-01
-3.6000	0.000E+00	5.459E-02	1.084E-01	1.606E-01	2.104E-01	2.569E-01	2.990E-01	3.354E-01	3.649E-01	3.851E-01	3.926E-01
-3.0000	0.000E+00	5.182E-02	1.029E-01	1.525E-01	1.997E-01	2.438E-01	2.838E-01	3.184E-01	3.463E-01	3.655E-01	3.727E-01
-2.4000	0.000E+00	4.849E-02	9.628E-02	1.427E-01	1.869E-01	2.282E-01	2.655E-01	2.979E-01	3.241E-01	3.420E-01	3.487E-01
-1.8000	0.000E+00	4.484E-02	8.905E-02	1.319E-01	1.729E-01	2.110E-01	2.456E-01	2.755E-01	2.997E-01	3.163E-01	3.225E-01
-1.2000	0.000E+00	4.107E-02	8.156E-02	1.208E-01	1.583E-01	1.933E-01	2.249E-01	2.524E-01	2.745E-01	2.897E-01	2.954E-01
-0.6000	0.000E+00	3.728E-02	7.403E-02	1.097E-01	1.437E-01	1.754E-01	2.042E-01	2.291E-01	2.492E-01	2.630E-01	2.681E-01
0.0000	0.000E+00	3.354E-02	6.660E-02	9.869E-02	1.293E-01	1.578E-01	1.837E-01	2.061E-01	2.242E-01	2.366E-01	2.412E-01
0.6000	0.000E+00	2.988E-02	5.934E-02	8.792E-02	1.152E-01	1.406E-01	1.636E-01	1.836E-01	1.997E-01	2.108E-01	2.149E-01
1.2000	0.000E+00	2.632E-02	5.226E-02	7.743E-02	1.014E-01	1.238E-01	1.441E-01	1.617E-01	1.759E-01	1.856E-01	1.892E-01
1.8000	0.000E+00	2.285E-02	4.536E-02	6.722E-02	8.806E-02	1.075E-01	1.251E-01	1.404E-01	1.527E-01	1.611E-01	1.643E-01
2.4000	0.000E+00	1.946E-02	3.865E-02	5.727E-02	7.502E-02	9.158E-02	1.066E-01	1.196E-01	1.301E-01	1.373E-01	1.400E-01
3.0000	0.000E+00	1.616E-02	3.209E-02	4.755E-02	6.230E-02	7.605E-02	8.850E-02	9.931E-02	1.080E-01	1.140E-01	1.162E-01

3.6000	0.000E+00	1.293E-02	2.567E-02	3.804E-02	4.983E-02	6.083E-02	7.079E-02	7.943E-02	8.640E-02	9.119E-02	9.297E-02
4.2000	0.000E+00	9.748E-03	1.936E-02	2.868E-02	3.757E-02	4.587E-02	5.338E-02	5.990E-02	6.515E-02	6.876E-02	7.010E-02
4.8000	0.000E+00	6.609E-03	1.312E-02	1.945E-02	2.548E-02	3.110E-02	3.619E-02	4.061E-02	4.417E-02	4.662E-02	4.753E-02
5.4000	0.000E+00	3.498E-03	6.946E-03	1.029E-02	1.348E-02	1.646E-02	1.916E-02	2.150E-02	2.338E-02	2.468E-02	2.516E-02
6.0000	0.000E+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X = 0.00

X\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.0000	0.000E+00	5.575E-02	1.107E-01	1.640E-01	2.149E-01	2.623E-01	3.053E-01	3.426E-01	3.726E-01	3.933E-01	4.009E-01
-5.4000	0.000E+00	5.633E-02	1.119E-01	1.658E-01	2.171E-01	2.651E-01	3.085E-01	3.461E-01	3.765E-01	3.974E-01	4.051E-01
-4.8000	0.000E+00	5.667E-02	1.125E-01	1.667E-01	2.184E-01	2.666E-01	3.103E-01	3.482E-01	3.787E-01	3.997E-01	4.075E-01
-4.2000	0.000E+00	5.606E-02	1.113E-01	1.649E-01	2.161E-01	2.638E-01	3.070E-01	3.444E-01	3.746E-01	3.954E-01	4.031E-01
-3.6000	0.000E+00	5.434E-02	1.079E-01	1.599E-01	2.095E-01	2.557E-01	2.976E-01	3.339E-01	3.632E-01	3.833E-01	3.908E-01
-3.0000	0.000E+00	5.171E-02	1.027E-01	1.522E-01	1.993E-01	2.433E-01	2.832E-01	3.178E-01	3.456E-01	3.648E-01	3.719E-01
-2.4000	0.000E+00	4.847E-02	9.625E-02	1.426E-01	1.868E-01	2.281E-01	2.654E-01	2.978E-01	3.239E-01	3.419E-01	3.486E-01
-1.8000	0.000E+00	4.488E-02	8.912E-02	1.321E-01	1.730E-01	2.112E-01	2.458E-01	2.758E-01	3.000E-01	3.166E-01	3.228E-01
-1.2000	0.000E+00	4.114E-02	8.169E-02	1.210E-01	1.586E-01	1.936E-01	2.253E-01	2.528E-01	2.749E-01	2.902E-01	2.958E-01
-0.6000	0.000E+00	3.736E-02	7.419E-02	1.099E-01	1.440E-01	1.758E-01	2.046E-01	2.296E-01	2.497E-01	2.636E-01	2.687E-01
0.0000	0.000E+00	3.363E-02	6.677E-02	9.894E-02	1.296E-01	1.582E-01	1.841E-01	2.066E-01	2.247E-01	2.372E-01	2.418E-01
0.6000	0.000E+00	2.996E-02	5.950E-02	8.816E-02	1.155E-01	1.410E-01	1.641E-01	1.841E-01	2.002E-01	2.113E-01	2.155E-01
1.2000	0.000E+00	2.639E-02	5.240E-02	7.765E-02	1.017E-01	1.242E-01	1.445E-01	1.622E-01	1.764E-01	1.862E-01	1.898E-01
1.8000	0.000E+00	2.291E-02	4.550E-02	6.741E-02	8.831E-02	1.078E-01	1.255E-01	1.408E-01	1.531E-01	1.616E-01	1.648E-01
2.4000	0.000E+00	1.952E-02	3.876E-02	5.744E-02	7.524E-02	9.185E-02	1.069E-01	1.199E-01	1.305E-01	1.377E-01	1.404E-01
3.0000	0.000E+00	1.621E-02	3.219E-02	4.769E-02	6.248E-02	7.627E-02	8.876E-02	9.960E-02	1.083E-01	1.143E-01	1.166E-01
3.6000	0.000E+00	1.297E-02	2.575E-02	3.815E-02	4.998E-02	6.101E-02	7.100E-02	7.967E-02	8.665E-02	9.146E-02	9.324E-02
4.2000	0.000E+00	9.776E-03	1.941E-02	2.876E-02	3.768E-02	4.600E-02	5.354E-02	6.007E-02	6.534E-02	6.896E-02	7.030E-02
4.8000	0.000E+00	6.623E-03	1.316E-02	1.950E-02	2.555E-02	3.119E-02	3.630E-02	4.073E-02	4.430E-02	4.675E-02	4.767E-02
5.4000	0.000E+00	3.508E-03	6.965E-03	1.032E-02	1.352E-02	1.650E-02	1.921E-02	2.155E-02	2.344E-02	2.474E-02	2.523E-02
6.0000	0.000E+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X = -2.46

X\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.0000	0.000E+00	5.704E-02	1.133E-01	1.678E-01	2.198E-01	2.684E-01	3.123E-01	3.505E-01	3.812E-01	4.023E-01	4.102E-01
-5.4000	0.000E+00	5.751E-02	1.142E-01	1.692E-01	2.217E-01	2.706E-01	3.149E-01	3.534E-01	3.844E-01	4.057E-01	4.136E-01
-4.8000	0.000E+00	5.758E-02	1.143E-01	1.694E-01	2.219E-01	2.709E-01	3.153E-01	3.538E-01	3.848E-01	4.062E-01	4.141E-01
-4.2000	0.000E+00	5.666E-02	1.125E-01	1.667E-01	2.184E-01	2.666E-01	3.103E-01	3.482E-01	3.787E-01	3.997E-01	4.075E-01
-3.6000	0.000E+00	5.468E-02	1.086E-01	1.609E-01	2.108E-01	2.573E-01	2.994E-01	3.360E-01	3.654E-01	3.857E-01	3.932E-01
-3.0000	0.000E+00	5.186E-02	1.030E-01	1.526E-01	1.999E-01	2.440E-01	2.840E-01	3.186E-01	3.465E-01	3.658E-01	3.729E-01
-2.4000	0.000E+00	4.849E-02	9.629E-02	1.427E-01	1.869E-01	2.282E-01	2.655E-01	2.980E-01	3.241E-01	3.420E-01	3.487E-01
-1.8000	0.000E+00	4.483E-02	8.902E-02	1.319E-01	1.728E-01	2.109E-01	2.455E-01	2.755E-01	2.996E-01	3.162E-01	3.224E-01
-1.2000	0.000E+00	4.105E-02	8.151E-02	1.208E-01	1.582E-01	1.931E-01	2.248E-01	2.522E-01	2.743E-01	2.895E-01	2.952E-01
-0.6000	0.000E+00	3.725E-02	7.397E-02	1.096E-01	1.436E-01	1.753E-01	2.040E-01	2.289E-01	2.490E-01	2.628E-01	2.679E-01
0.0000	0.000E+00	3.351E-02	6.654E-02	9.860E-02	1.292E-01	1.577E-01	1.835E-01	2.059E-01	2.240E-01	2.364E-01	2.410E-01
0.6000	0.000E+00	2.985E-02	5.928E-02	8.784E-02	1.151E-01	1.405E-01	1.635E-01	1.834E-01	1.995E-01	2.106E-01	2.147E-01
1.2000	0.000E+00	2.629E-02	5.220E-02	7.735E-02	1.013E-01	1.237E-01	1.440E-01	1.615E-01	1.757E-01	1.854E-01	1.891E-01
1.8000	0.000E+00	2.282E-02	4.532E-02	6.715E-02	8.797E-02	1.074E-01	1.250E-01	1.402E-01	1.525E-01	1.610E-01	1.641E-01
2.4000	0.000E+00	1.944E-02	3.861E-02	5.721E-02	7.495E-02	9.149E-02	1.065E-01	1.195E-01	1.299E-01	1.372E-01	1.398E-01

3.0000	0.000E+00	1.615E-02	3.206E-02	4.750E-02	6.223E-02	7.597E-02	8.841E-02	9.921E-02	1.079E-01	1.139E-01	1.161E-01
3.6000	0.000E+00	1.291E-02	2.564E-02	3.800E-02	4.978E-02	6.077E-02	7.072E-02	7.935E-02	8.631E-02	9.109E-02	9.287E-02
4.2000	0.000E+00	9.738E-03	1.934E-02	2.865E-02	3.753E-02	4.582E-02	5.333E-02	5.984E-02	6.508E-02	6.869E-02	7.003E-02
4.8000	0.000E+00	6.603E-03	1.311E-02	1.943E-02	2.545E-02	3.107E-02	3.616E-02	4.057E-02	4.413E-02	4.657E-02	4.748E-02
5.4000	0.000E+00	3.495E-03	6.940E-03	1.028E-02	1.347E-02	1.645E-02	1.914E-02	2.148E-02	2.336E-02	2.465E-02	2.513E-02
6.0000	0.000E+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X = -4.92

X\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.0000	0.000E+00	5.841E-02	1.160E-01	1.719E-01	2.251E-01	2.748E-01	3.199E-01	3.589E-01	3.904E-01	4.120E-01	4.201E-01
-5.4000	0.000E+00	5.879E-02	1.167E-01	1.730E-01	2.266E-01	2.766E-01	3.219E-01	3.613E-01	3.929E-01	4.147E-01	4.228E-01
-4.8000	0.000E+00	5.857E-02	1.163E-01	1.723E-01	2.258E-01	2.756E-01	3.208E-01	3.599E-01	3.915E-01	4.132E-01	4.212E-01
-4.2000	0.000E+00	5.732E-02	1.138E-01	1.687E-01	2.209E-01	2.697E-01	3.139E-01	3.522E-01	3.831E-01	4.043E-01	4.122E-01
-3.6000	0.000E+00	5.505E-02	1.093E-01	1.620E-01	2.122E-01	2.590E-01	3.015E-01	3.383E-01	3.679E-01	3.883E-01	3.959E-01
-3.0000	0.000E+00	5.202E-02	1.033E-01	1.531E-01	2.005E-01	2.448E-01	2.849E-01	3.197E-01	3.477E-01	3.670E-01	3.741E-01
-2.4000	0.000E+00	4.853E-02	9.635E-02	1.428E-01	1.870E-01	2.283E-01	2.657E-01	2.982E-01	3.243E-01	3.423E-01	3.490E-01
-1.8000	0.000E+00	4.478E-02	8.893E-02	1.318E-01	1.726E-01	2.107E-01	2.452E-01	2.752E-01	2.993E-01	3.159E-01	3.221E-01
-1.2000	0.000E+00	4.096E-02	8.133E-02	1.205E-01	1.579E-01	1.927E-01	2.243E-01	2.517E-01	2.737E-01	2.889E-01	2.946E-01
-0.6000	0.000E+00	3.715E-02	7.377E-02	1.093E-01	1.432E-01	1.748E-01	2.034E-01	2.283E-01	2.483E-01	2.620E-01	2.672E-01
0.0000	0.000E+00	3.340E-02	6.633E-02	9.828E-02	1.288E-01	1.572E-01	1.829E-01	2.052E-01	2.232E-01	2.356E-01	2.402E-01
0.6000	0.000E+00	2.975E-02	5.907E-02	8.753E-02	1.147E-01	1.400E-01	1.629E-01	1.828E-01	1.988E-01	2.098E-01	2.139E-01
1.2000	0.000E+00	2.619E-02	5.201E-02	7.707E-02	1.010E-01	1.232E-01	1.434E-01	1.609E-01	1.751E-01	1.848E-01	1.884E-01
1.8000	0.000E+00	2.274E-02	4.515E-02	6.690E-02	8.764E-02	1.070E-01	1.245E-01	1.397E-01	1.520E-01	1.604E-01	1.635E-01
2.4000	0.000E+00	1.937E-02	3.846E-02	5.699E-02	7.466E-02	9.114E-02	1.061E-01	1.190E-01	1.295E-01	1.366E-01	1.393E-01
3.0000	0.000E+00	1.608E-02	3.194E-02	4.732E-02	6.200E-02	7.568E-02	8.808E-02	9.883E-02	1.075E-01	1.135E-01	1.157E-01
3.6000	0.000E+00	1.287E-02	2.555E-02	3.785E-02	4.959E-02	6.054E-02	7.045E-02	7.905E-02	8.598E-02	9.075E-02	9.252E-02
4.2000	0.000E+00	9.702E-03	1.926E-02	2.855E-02	3.739E-02	4.565E-02	5.313E-02	5.961E-02	6.484E-02	6.843E-02	6.977E-02
4.8000	0.000E+00	6.579E-03	1.306E-02	1.936E-02	2.536E-02	3.095E-02	3.603E-02	4.042E-02	4.397E-02	4.640E-02	4.731E-02
5.4000	0.000E+00	3.483E-03	6.916E-03	1.025E-02	1.343E-02	1.639E-02	1.907E-02	2.140E-02	2.328E-02	2.457E-02	2.505E-02
6.0000	0.000E+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X = -7.38

X\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.0000	0.000E+00	5.952E-02	1.182E-01	1.751E-01	2.294E-01	2.801E-01	3.259E-01	3.657E-01	3.978E-01	4.198E-01	4.280E-01
-5.4000	0.000E+00	5.984E-02	1.188E-01	1.761E-01	2.307E-01	2.816E-01	3.277E-01	3.677E-01	3.999E-01	4.221E-01	4.303E-01
-4.8000	0.000E+00	5.939E-02	1.179E-01	1.747E-01	2.289E-01	2.795E-01	3.252E-01	3.649E-01	3.969E-01	4.189E-01	4.271E-01
-4.2000	0.000E+00	5.786E-02	1.149E-01	1.702E-01	2.230E-01	2.723E-01	3.168E-01	3.555E-01	3.867E-01	4.081E-01	4.161E-01
-3.6000	0.000E+00	5.536E-02	1.099E-01	1.629E-01	2.134E-01	2.605E-01	3.031E-01	3.401E-01	3.699E-01	3.905E-01	3.981E-01
-3.0000	0.000E+00	5.216E-02	1.036E-01	1.535E-01	2.010E-01	2.454E-01	2.856E-01	3.205E-01	3.486E-01	3.679E-01	3.751E-01
-2.4000	0.000E+00	4.855E-02	9.640E-02	1.428E-01	1.871E-01	2.284E-01	2.659E-01	2.983E-01	3.245E-01	3.424E-01	3.491E-01
-1.8000	0.000E+00	4.475E-02	8.885E-02	1.317E-01	1.725E-01	2.105E-01	2.450E-01	2.749E-01	2.990E-01	3.156E-01	3.218E-01
-1.2000	0.000E+00	4.089E-02	8.119E-02	1.203E-01	1.576E-01	1.924E-01	2.239E-01	2.512E-01	2.733E-01	2.884E-01	2.940E-01
-0.6000	0.000E+00	3.706E-02	7.359E-02	1.090E-01	1.429E-01	1.744E-01	2.030E-01	2.277E-01	2.477E-01	2.614E-01	2.665E-01
0.0000	0.000E+00	3.331E-02	6.615E-02	9.802E-02	1.284E-01	1.567E-01	1.824E-01	2.047E-01	2.226E-01	2.350E-01	2.396E-01
0.6000	0.000E+00	2.966E-02	5.890E-02	8.727E-02	1.143E-01	1.396E-01	1.624E-01	1.823E-01	1.982E-01	2.092E-01	2.133E-01
1.2000	0.000E+00	2.611E-02	5.185E-02	7.683E-02	1.007E-01	1.229E-01	1.430E-01	1.605E-01	1.745E-01	1.842E-01	1.878E-01
1.8000	0.000E+00	2.267E-02	4.501E-02	6.669E-02	8.736E-02	1.066E-01	1.241E-01	1.393E-01	1.515E-01	1.599E-01	1.630E-01

2.4000	0.000E+00	1.931E-02	3.834E-02	5.681E-02	7.443E-02	9.086E-02	1.057E-01	1.186E-01	1.290E-01	1.362E-01	1.389E-01
3.0000	0.000E+00	1.603E-02	3.184E-02	4.717E-02	6.180E-02	7.544E-02	8.780E-02	9.852E-02	1.072E-01	1.131E-01	1.153E-01
3.6000	0.000E+00	1.283E-02	2.547E-02	3.774E-02	4.943E-02	6.035E-02	7.023E-02	7.880E-02	8.571E-02	9.046E-02	9.223E-02
4.2000	0.000E+00	9.671E-03	1.920E-02	2.846E-02	3.728E-02	4.551E-02	5.296E-02	5.943E-02	6.464E-02	6.822E-02	6.955E-02
4.8000	0.000E+00	6.559E-03	1.302E-02	1.930E-02	2.528E-02	3.086E-02	3.592E-02	4.030E-02	4.383E-02	4.626E-02	4.716E-02
5.4000	0.000E+00	3.473E-03	6.896E-03	1.022E-02	1.339E-02	1.634E-02	1.902E-02	2.134E-02	2.321E-02	2.450E-02	2.498E-02
6.0000	0.000E+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X = -9.84

X\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.0000	0.000E+00	6.033E-02	1.198E-01	1.775E-01	2.326E-01	2.839E-01	3.304E-01	3.707E-01	4.032E-01	4.256E-01	4.339E-01
-5.4000	0.000E+00	6.064E-02	1.204E-01	1.784E-01	2.337E-01	2.853E-01	3.321E-01	3.726E-01	4.053E-01	4.277E-01	4.361E-01
-4.8000	0.000E+00	6.002E-02	1.192E-01	1.766E-01	2.314E-01	2.824E-01	3.287E-01	3.688E-01	4.011E-01	4.234E-01	4.316E-01
-4.2000	0.000E+00	5.828E-02	1.157E-01	1.715E-01	2.246E-01	2.742E-01	3.191E-01	3.581E-01	3.895E-01	4.111E-01	4.191E-01
-3.6000	0.000E+00	5.559E-02	1.104E-01	1.636E-01	2.143E-01	2.616E-01	3.044E-01	3.416E-01	3.715E-01	3.921E-01	3.998E-01
-3.0000	0.000E+00	5.226E-02	1.038E-01	1.538E-01	2.014E-01	2.459E-01	2.862E-01	3.211E-01	3.493E-01	3.686E-01	3.758E-01
-2.4000	0.000E+00	4.857E-02	9.644E-02	1.429E-01	1.872E-01	2.285E-01	2.660E-01	2.984E-01	3.246E-01	3.426E-01	3.493E-01
-1.8000	0.000E+00	4.471E-02	8.879E-02	1.316E-01	1.723E-01	2.104E-01	2.449E-01	2.747E-01	2.988E-01	3.154E-01	3.216E-01
-1.2000	0.000E+00	4.083E-02	8.108E-02	1.201E-01	1.574E-01	1.921E-01	2.236E-01	2.509E-01	2.729E-01	2.880E-01	2.936E-01
-0.6000	0.000E+00	3.699E-02	7.346E-02	1.088E-01	1.426E-01	1.741E-01	2.026E-01	2.273E-01	2.472E-01	2.609E-01	2.660E-01
0.0000	0.000E+00	3.324E-02	6.601E-02	9.781E-02	1.281E-01	1.564E-01	1.820E-01	2.043E-01	2.222E-01	2.345E-01	2.391E-01
0.6000	0.000E+00	2.959E-02	5.876E-02	8.707E-02	1.141E-01	1.392E-01	1.621E-01	1.818E-01	1.978E-01	2.087E-01	2.128E-01
1.2000	0.000E+00	2.605E-02	5.173E-02	7.665E-02	1.004E-01	1.226E-01	1.427E-01	1.601E-01	1.741E-01	1.838E-01	1.873E-01
1.8000	0.000E+00	2.261E-02	4.490E-02	6.653E-02	8.715E-02	1.064E-01	1.238E-01	1.389E-01	1.511E-01	1.595E-01	1.626E-01
2.4000	0.000E+00	1.926E-02	3.825E-02	5.667E-02	7.424E-02	9.063E-02	1.055E-01	1.184E-01	1.287E-01	1.359E-01	1.385E-01
3.0000	0.000E+00	1.599E-02	3.176E-02	4.706E-02	6.165E-02	7.525E-02	8.758E-02	9.827E-02	1.069E-01	1.128E-01	1.150E-01
3.6000	0.000E+00	1.279E-02	2.540E-02	3.764E-02	4.931E-02	6.020E-02	7.006E-02	7.861E-02	8.550E-02	9.024E-02	9.200E-02
4.2000	0.000E+00	9.648E-03	1.916E-02	2.839E-02	3.719E-02	4.540E-02	5.283E-02	5.928E-02	6.448E-02	6.805E-02	6.938E-02
4.8000	0.000E+00	6.543E-03	1.299E-02	1.925E-02	2.522E-02	3.079E-02	3.583E-02	4.020E-02	4.373E-02	4.615E-02	4.705E-02
5.4000	0.000E+00	3.465E-03	6.881E-03	1.020E-02	1.336E-02	1.630E-02	1.898E-02	2.129E-02	2.316E-02	2.444E-02	2.492E-02
6.0000	0.000E+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

INTERCONTAINER SLOT BOTTOM STREAM FUNCTION

FOR SLOT AT LOCATION X =-12.30

X\Z=	0.00E+00	1.00E-01	2.00E-01	3.00E-01	4.00E-01	5.00E-01	6.00E-01	7.00E-01	8.00E-01	9.00E-01	1.00E+00
-6.0000	0.000E+00	6.085E-02	1.208E-01	1.790E-01	2.345E-01	2.863E-01	3.332E-01	3.739E-01	4.067E-01	4.292E-01	4.376E-01
-5.4000	0.000E+00	6.119E-02	1.215E-01	1.800E-01	2.358E-01	2.879E-01	3.351E-01	3.760E-01	4.089E-01	4.316E-01	4.400E-01
-4.8000	0.000E+00	6.047E-02	1.201E-01	1.779E-01	2.331E-01	2.845E-01	3.311E-01	3.716E-01	4.041E-01	4.265E-01	4.349E-01
-4.2000	0.000E+00	5.858E-02	1.163E-01	1.724E-01	2.258E-01	2.756E-01	3.208E-01	3.600E-01	3.915E-01	4.132E-01	4.213E-01
-3.6000	0.000E+00	5.576E-02	1.107E-01	1.641E-01	2.149E-01	2.624E-01	3.054E-01	3.426E-01	3.727E-01	3.933E-01	4.010E-01
-3.0000	0.000E+00	5.234E-02	1.039E-01	1.540E-01	2.017E-01	2.463E-01	2.866E-01	3.216E-01	3.498E-01	3.692E-01	3.764E-01
-2.4000	0.000E+00	4.858E-02	9.647E-02	1.429E-01	1.873E-01	2.286E-01	2.660E-01	2.985E-01	3.247E-01	3.427E-01	3.494E-01
-1.8000	0.000E+00	4.470E-02	8.875E-02	1.315E-01	1.723E-01	2.103E-01	2.448E-01	2.746E-01	2.987E-01	3.153E-01	3.214E-01
-1.2000	0.000E+00	4.079E-02	8.100E-02	1.200E-01	1.572E-01	1.919E-01	2.234E-01	2.507E-01	2.726E-01	2.877E-01	2.934E-01
-0.6000	0.000E+00	3.695E-02	7.337E-02	1.087E-01	1.424E-01	1.739E-01	2.023E-01	2.270E-01	2.469E-01	2.606E-01	2.657E-01
0.0000	0.000E+00	3.319E-02	6.591E-02	9.767E-02	1.279E-01	1.562E-01	1.818E-01	2.040E-01	2.218E-01	2.341E-01	2.387E-01
0.6000	0.000E+00	2.955E-02	5.867E-02	8.694E-02	1.139E-01	1.390E-01	1.618E-01	1.816E-01	1.975E-01	2.084E-01	2.125E-01
1.2000	0.000E+00	2.601E-02	5.164E-02	7.652E-02	1.002E-01	1.224E-01	1.424E-01	1.598E-01	1.738E-01	1.835E-01	1.870E-01

1.8000	0.000E+00	2.257E-02	4.482E-02	6.641E-02	8.700E-02	1.062E-01	1.236E-01	1.387E-01	1.508E-01	1.592E-01	1.623E-01
2.4000	0.000E+00	1.923E-02	3.818E-02	5.657E-02	7.411E-02	9.047E-02	1.053E-01	1.181E-01	1.285E-01	1.356E-01	1.383E-01
3.0000	0.000E+00	1.597E-02	3.170E-02	4.698E-02	6.154E-02	7.512E-02	8.743E-02	9.810E-02	1.067E-01	1.126E-01	1.148E-01
3.6000	0.000E+00	1.277E-02	2.536E-02	3.758E-02	4.923E-02	6.009E-02	6.994E-02	7.847E-02	8.535E-02	9.008E-02	9.184E-02
4.2000	0.000E+00	9.631E-03	1.912E-02	2.834E-02	3.712E-02	4.532E-02	5.274E-02	5.918E-02	6.437E-02	6.793E-02	6.926E-02
4.8000	0.000E+00	6.532E-03	1.297E-02	1.922E-02	2.518E-02	3.073E-02	3.577E-02	4.013E-02	4.365E-02	4.607E-02	4.697E-02
5.4000	0.000E+00	3.460E-03	6.870E-03	1.018E-02	1.334E-02	1.628E-02	1.895E-02	2.126E-02	2.312E-02	2.440E-02	2.488E-02
6.0000	0.000E+00	4.011E-04	7.964E-04	1.180E-03	1.546E-03	1.887E-03	2.196E-03	2.465E-03	2.681E-03	2.829E-03	2.884E-03

DIMENSIONLESS MASS PICK-UP

SLOT LOCATION	MASS PICK-UP
0.24	1.10524E+00
0.19	1.10263E+00
0.14	1.09906E+00
0.10	1.09461E+00
0.05	1.08914E+00
0.00	1.08615E+00
-0.05	1.09025E+00
-0.10	1.09582E+00
-0.14	1.10026E+00
-0.19	1.10380E+00
-0.24	1.10638E+00

TEST CASE 5, HEPTANE SPILL (D.P.)

TC = 10.0 DEC C   CC = 113.55 GM/M**3   P = 20.05 MM HG

HOLD VOID VOLUME = 2407.000 M**3
AIR CHANGES/HOUR = 1.496 BASED ON TOTAL HOLD VOLUME

TOTAL MASS PICK-UP   2.62452E-02 GM/SEC

VAPOR CONCENTRATION IN EXHAUST AIR = 2.62452E-02 GM/M**3

APPENDIX 3.

Computer Code Listing

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 ***, SEE OOCUMENTATION PACKAGE, 04-1C1M99.

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              C      SEALAND PROJECT, PROGRAM #10
              C      WRITTEN BY JOHN A. ROCKETT, JUNE 1979
              C
              C      REF.: H.BAUM, THEORETICAL INVESTIGATION OF THE FLUIO MOTIONS
              C      IN A CONTAINER SHIP HOLD. PRELIMINARY REPORT, JUNE, 1978.
              C
              C      THIS VERSION IS BASED ON A FURTHER SIMPLIFICATION OF THE PROBLEM:
              C         THE TEMPERATURE FIELD STRONGLY STRATIFIES THE AIR
              C            THE STRATIFICATION IS STABLE.
              C         THE SIOE ANO BULKHEAO VOIOS ARE THE SAME THICKNESS ANO ESSENTIALLY
              C            FREE OF OBSTRUCTIONS TO VERTICAL AIR MOVEMENT.  THIS ALLOWS
              C            A SINGLE SLOT TO APPROXIMATE THE INTERESTING FLOW IN THESE
              C            LARGE VOIOS.
              C         THIN INTER-CONTAINER VOIOS CONNECT TO THE ABOVE MAIN VOID AT
              C            WIDELY SPACED INTERVALS. THIS IS NOT STRICTLY TRUE SINCE
              C            THE MAIN VOIO IS ABOUT 2 METERS THICK AND THE INTER-CONTAINER
              C            SLOTS MEET IT AT APPROXIMATELY 3 METER INTERVALS.
              C
              C      THE MAIN PROGRAM MANAGES THE WHOLE CALCULATION
              C
000000I              DIMENSION XS(11),UB(10,11),UBO(11),W(10,11),WO(11)
                    &,USLOT(31,11)
                    &,ZPSI(31,31),XPSI(31),TOTAL(11)
              C
              C
000006I        10    FORMAT(//,5X,'CONTAINER SHIP VENTILATION STUOY',//,10X,
                    &'VERSION 10 - JUNE, 1979')
000050I        15    FORMAT(I10)
000054I        20    FORMAT(//,10X,'SCALING PARAMETERS',//,12X,'GRASH   =',
                    +  1PE12.4,5X,'OMEGA =',1PE12.4,//,12X,'SQRT(F) =',1PE12.4)
0000A8I        30    FORMAT(//,10X,'THE SCALE LENGTH FOR THE VOIO, X= XL*FS, IS LESS TH
                    &AN THE VOID WIDTH,, YB.'//,15X,'X =',F7.2,', YB =',F7.2,/,
                    & 10X,'THIS MODEL ASSUMES THE VOIO IS NARROW COMPARED TO THE SCALE
                    &LENGTH')
000158I        40    FORMAT(/,12X,'GRSLOT  =',1PE12.4,5X,'OMSLOT=',1PE12.4,
                    +  /,12X,'SQRT(FS)=',1PE12.4)
000194I        50    FORMAT(//,10X,'THE SCALE LENGTH FOR THE SLOT, X= XSLOT*FSSLOT, IS
                    &LESS THAN THE SLOT WIDTH, YSLOT.',//,15X,'X =',F7.2, ', YSLOT =',
                    & F7.2,//,10X,'THE MODEL REQUIRES THAT THE SLOT BE NARROW COMPARED T
                    &O THE SCALE LENGTH.')
000256I        52    FORMAT(//,10X,'THE MOOEL ASSUMES THE SLOTS ARE WIDELY SPACEO',
                    &  /,10X,'COMPARED TO THE VOID WIDTH (AFTER SCALING).',
                    &  /,10X,'INTERCONTAINER SLOT SPACING =',F5.2,' M',
                    &  //,10X,'MAIN VOID WIDTH             =',F5.2,' M',
                    &  //,10X,'SCALEO SPACING/VOID WIDTH  =',1PE13.5)
000336I        54    FORMAT(//,10X,'*****  THIS SHOULO BE MUCH LESS THAN 1!  *****')
00036CI        56    FORMAT(//,10X,'MAIN SUCTION',//,12X,'XSINK =',F7.4,' M',
                    &  5X,'YSINK =',F7.4,' M')
0003A6I        58    FORMAT(///,10X,'YSINK =',F5.2,'IS TOO CLOSE TO TANK TOP, Y = 0.',/,
                    & 10X,'MOVE IT UP THE RADIUS OF A REASONABLE OUCT,',/
                    & 10X,'YSINK = 0.05')
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00041CI    60   FORMAT(//,12X,'HOLD VOID VOLUME =',F10.3,' M**3',/
               &   ,12X,'AIR CHANGES/HOUR =',F10.3,' BASED ON TOTAL HOLD VOLUME')
000478I    70   FORMAT(//,10X,'SUCTION MOVED TO AVOID SLOT-VOID INTERSECTION',/,
               +  10X,'XSINK =',1PE10.2,'TO XSINK =',1PE10.2)
000402I    75   FORMAT(4I5,1P4E15.6)
0004E0I    90   FORMAT(///,10X,'TOTAL MASS PICK-UP',15X,1PE15.5,2X,'GM/SEC')
00050EI    95   FORMAT(//,10X,'VAPOR CONCENTRATION IN EXHAUST AIR =',1PE13.5,
               &  2X,'GM/M**3')
             C
00054CI         CALL CARCON(6,1)
001E6CI         WRITE(6,10)
             C
             C      AXIAL AND TRANSVERSE VELOCITIES FOR THE SLOT BOTTOM, IN
             C      DIMENSIONLESS FORM, ARE INDEPENDENT OF THE SLOT GEOMETRY
             C      AND OTHER EXTERNAL CONDITIONS AND CAN BE CALCULATED ONCE
             C      FOR ALL CASES.
             C
001E88I         CALL INTEG1(UB,UBO)
001EA4I         CALL INTEG2(UB,UBO,W,WO)
             C
             C      PRINT GEOMETRY INDEPENDENT RESULTS.
             C
001EC8I         CALL PRINT(UB,UBO,W,WO)
             C
             C      THE PROGRAM IS SET UP TO COMPUTE MULTIPLE GEOMETRIC OR
             C        THERMAL CASES, LOOPING BACK TO LINE 100, BELOW, FOR
             C        EACH CASE.
             C
             C      READ THE NUMBER OF CASES TO BE TREATED
             C
001EECI         READ(5,15) NGEOMS
001F0CI         NGEOM=0
001F14I   100   CONTINUE
001F14I         NGEOM=NGEOM + 1
             C
001F22I         CALL INPUT(TK,DELT,XL,YB,H,D,XSLOT,YSLOT,NXSLOT,OSLOT,
               &  NSLOTS,XS,XSINK,YSINK,VTOT,VVOID,NCHEMS,SPACE)
             C
             C      CALCULATION OF BASIC PARAMETERS OF THE MAIN AND SLOT FLOWS
             C
             C      FIND SCALING PARAMETERS
             C
             C      FOR AIR ASSUME
             C         DENSITY   0.001205 GM/CM**3
             C         VISCOSITY 180.8    MICROPOISE
             C         PR        0.74
             C
001F7CI         PR=0.74
001F88I         VISC=0.01808
001F94I         VISKIN=0.15004E-4
001FA0I         GRAV=9.80665
```

```
                 C
                 C      MAIN VOID PARAMETERS
                 C
        001FACI         D3=D**3
        001FC0I         GRASH= GRAV*DELT*D3/(TK*VISKIN*VISKIN)
        001FECI         OMEGA=((GRASH*PR*D/H)**0.25)/SQRT(2.)
        00204AI         F=(3./(8.*(OMEGA**3)))*((SINH(2.*OMEGA)-SIN(2.*OMEGA))/
                       &  ((COSH(OMEGA))**2-(SIN(OMEGA))**2))
        002124I         FS=SQRT(F)
        002142I         WRITE(6,20) GRASH,OMEGA,FS
                 C
                 C      INTERCONTAINER SLOTS
                 C
        002168I         DSL3=DSLOT**3
        00217CI         GRSLOT= GRAV*DELT*DSL3/(TK*VISKIN*VISKIN)
        0021A8I         OMSLOT= ((GRSLOT*PR*DSLOT/H)**0.25)/SQRT(2.)
        002206I         FSLOT= (3./(8.*(OMSLOT**3)))*((SINH(2.*OMSLOT)-SIN(2.*OMSLOT))/
                       &((COSH(OMSLOT))**2-(SIN(OMSLOT))**2))
        0022E0I         FSSLOT=SQRT(FSLOT)
        0022FEI         WRITE(6,40) GRSLOT,OMSLOT,FSSLOT
                 C
                 C      THE MODEL ASSUMES THAT THERE ARE NO PRESSURE GRADIENTS
                 C        ACROSS THE NARROW DIMENSION OF THE VOID.
                 C        THIS IS VALID PROVIDED THE SCALE LENGTH, X=XL*FS, IS LARGE
                 C        COMPARED TO THE VOID WIDTH.
                 C      CHECK TO SEE THAT THIS RESTRICTION IS MET BY THE INPUT DATA.
                 C
        002324I         X=XL*FS
        002336I         IF(X.GT.YB) GO TO 150
        00234EI         WRITE(6,30) X,YB
        002370I         STOP
                 C
                 C      CHECK TO SEE THAT SLOT WIDTH IS LESS THAT SLOT SCALE LENGTH.
                 C
        002378I   150   CONTINUE
        002378I         X=XSLOT*FSSLOT
        00238AI         IF(X.GT.YSLOT) GO TO 200
        0023A2I         WRITE(6,50) X,YSLOT
        0023C4I         STOP
                 C
        0023CCI   200   CONTINUE
                 C
                 C      THE SLOTS SHOULD BE WIDELY SPACED COMPARED TO THE VOID WIDTH.
                 C        THIS MAY WELL NOT BE TRUE FOR SOME SHIPS.  WE NOTE THE
                 C        SCALED RATIO, BUT TAKE NO ACTION IF IT ISN'T LARGE.
                 C
        0023CCI         TEST=SPACE*FS
        0023DEI         RATIO = TEST/YB
        0023F0I         WRITE(6,52) SPACE,YB,RATIO
        002418I         IF(RATIO.LT.0.5) GO TO 250
        00243DI         WRITE(6,54)
```

```
                C
     00244CI      250  CONTINUE
                C
                C      WE WANT TO AVOID HAVING THE MAIN SUCTION (SINK) LIE ON A SLOT-VOID
                C        INTERSECTION.  IF IT DOES, MOVE IT HORIZONTALLY A DISTANCE LESS THAN
                C        THE SPATIAL RESOLUTION OF THE CALCULATION
                C
     00244CI           SAVE = XSINK
     002458I           NFLAG = 0
     002460I           DO 400 J = 1,NSLOTS
     002474I           TEST1 = XS(J) +0.05
     00248CI           TEST2 = XS(J) -0.05
     0024A4I           IF ((XSINK.LT.TEST1).AND.(XSINK.GE.XS(J))) GOTO 300
     0024D4I           IF ((XSINK.GT.TEST2).AND.(XSINK.LE.XS(J))) GOTO 350
     002504I      400  CONTINUE
     00251CI      300  XSINK = XSINK + 0.005*XL
     002534I           NFLAG =1
     00253CI           GOTO 401
     002542I      350  XSINK = XSINK - 0.005*XL
     00255CI           NFLAG = 1
     002564I      401  CONTINUE
     002564I           IF (NFLAG.GT.0) WRITE(6,70) SAVE,XSINK
                C
                C      CHECK TO SEE IF THE SUCTION IS TOO CLOSE TO THE TANK TOP.
                C        THE MODEL ASSUMES IT IS IN THE INTERIOR OF THE SPACE,
                C        NOT ON THE BOUNDARY.  IF IT IS LOW, MOVE IT UP TO 5 CM.
                C
     002598I           IF(YSINK.GE.0.05) GO TO 500
                C
     002580I           WRITE(6,58) YSINK
     0025D0I           YSINK = 0.05
                C
     0025DCI      500  WRITE(6,56) XSINK,YSINK
                C
                C      NOTE: QVOID AND QSLOT ARE BASED ON UNIT TOTAL FLOW. SINCE THEY
                C             ARE USED ONLY AS THE RATIO QSLOT/QVOID THIS IS OK.
                C            IT IS ASSUMED THAT NO MASS PICK-UP OCCURS IN THE
                C              MAIN VOID.
                C
     002600I           QSUM = D3*XL*F + NSLOTS*(DSL3*XSLOT*FSLOT)
     002630I           QVOID= (D3*XL*F/QSUM)
     002654I           QSLOT= (DSL3*XSLOT*FSLOT/QSUM)
                C
                C      WE WILL WANT TO PLOT STREAMLINES FOR THE FLOW ALONG THE SLOT
                C        BOTTOM AND THE PRESSURE AT THE OPEN END OF THE SLOT (SLOT-
                C        VOID INTERSECTION).  HOWEVER, ONLY THE VALUES FOR THE SLOTS
                C        CLOSEST TO AND FURTHEST FROM THE SUCTION ARE OF INTEREST
                C        SINCE THESE QUANTITIES DON'T VARY A GREAT DEAL.
                C
                C      IDENTIFY THE SLOT INDICIES, NMIN AND NMAX, FOR THE SLOTS CLOSEST
                C        TO AND FURTHEST FROM THE SUCTION.
```

```
                C
002672I               NMIN=0
00267AI               NMAX=0
002682I               REF1=0.
00268EI               REF2=XL
                C
00269AI               DO 550 J=1,NSLOTS
0026AEI               TEST=ABS(XS(J)-XSINK)
0026E2I               IF(TEST.GT.REF1) NMAX=J
002700I               IF(TEST.GT.REF1) REF1=TEST
00271EI               IF(TEST.LT.REF2) NMIN=J
00273CI               IF(TEST.LT.REF2) REF2=TEST
00275AI          550  CONTINUE
                C
                C     PUT HEAOER INFORMATION ON STREAMLINE PLOT FILE
                C
002772I               WRITE(7,75) NXSLOT,NSLOTS,NMIN,NMAX,XS(NMIN),XS(NMAX),XSINK,YSINK
                C
                C     PUT SLOT LOCATIONS, XS AND SUCTION LOCATION, XSINK, YSINK
                C       IN DIMENSIONLESS FORM IN VOID COOROINATE SYSTEM.
                C
0027D4I               DO 600 N=1,NSLOTS
0027E8I               XS(N)=XS(N)/XL
002806I          600  CONTINUE
00281EI               XSD=XSINK/XL
002830I               YSD=YSINK/(XL*FS)
                C
                C     SLOT FLOW IS BASED ON A PRESSURE DERIVED FROM THE MAIN VOIO.
                C     SLOT VARIABLES MUST BE CALCULATED FOR EACH SLOT
                C     SINCE EACH SLOT SEES A DIFFERENT END PRESSURE.
                C
                C     THE CALCULATION PROCEEDS AS FOLLOWS:
                C       FOR EACH SLOT IN TURN -
                C       1.) CALL SLOT1 - THIS SETS UP VALUES TO
                C           CALCULATE PARTIAL P/PARTIAL X FOR Y=0.  THIS IS THE
                C           AXIAL VELOCITY NEAR THE BOTTOM OF THE SLOT USLOT(X).
                C           USLOT IS CALCULATED BY CALLS FROM SLOT1 TO THE EXTERNAL
                C           FUNCTIONS GRAD (S10GRAD.FTN) AND PRESS (S10PRESS.FTN)
                C           AND IS TABULATEO, FOR EACH SLOT, N, FOR NXSLOT LOCATIONS,
                C           X(I), GIVING A MATRIX USLOT(I,N).
                C       2.) CALL STRM1 - THIS GENERATES STREAMLINES FOR THE FLOW
                C           ALONG THE SLOT BOTTOM USING WO (FROM INTEG2) ANO USLOT(I,N).
                C       3.) CALL PICUP1 - THIS INTEGRATES THE LOCAL MASS PICK-UP
                C           ALONG THE STREAMLINES FROM WHERE THEY LEAVE THE SIDE
                C           WALL OF THE SLOT TO WHERE THEY ENTER THE MAIN VOID.
                C           THE MASS PICK-UP OF THE INDIVIDUAL STREAM TUBES IS
                C           THEN INTEGRATED ACROSS THE END OF THE SLOT TO GIVE THE
                C           TOTAL PICK-UP FOR THAT SLOT.
                C       4.) THE CALCULATION THEN LOOPS BACK REPEATING THE ABOVE
                C           FOR EACH SLOT AND ADDING THE INOIVIOUAL SLOT MASS
                C           PICK-UPS TO GIVE THE TOTAL.
```

```
                C
00284AI               PICKUP = 0.
                C
002856I               DO 700 N=1,NSLOTS
00286AI               CALL SLOT1(NXSLOT,USLOT,N,XS,D3,DSL3,XL,XSLOT,FS
                     &  ,FSSLOT,XSD,YSD,QVOID,QSLOT,NSLOTS)
                C
002888I               CALL STRM1(NXSLOT,USLOT,WO,ZPSI,N,IMAX,XPSI,NMIN,NMAX)
                C
0028F0I               CALL PICUP1(NXSLOT,ZPSI,XPSI,USLOT,WO,UBO,TOTAL,N,IMAX)
                C
002928I               PICKUP = PICKUP + TOTAL(N)
002940I          700  CONTINUE
                C
                C     PRINT SLOT RESULTS.
                C
002958I               CALL PRINT1(XSLOT,NXSLOT,USLOT,XS,NSLOTS,XL,
                     &  WO,TOTAL)
                C
                C     COMPUTE DIMENSIONAL PICK-UP FOR SPECIFIC CHEMICALS AND
                C       VENTELATION RATES
                C
                C     GET DATA ON CHEMICAL
                C
00298CI               NCHEM =0
002994I          800  CONTINUE
002994I               CALL INPUT1(DIFFU,CO,TK,NFLOWS)
                C
                C     GET VENTELATION RATES TOBE USED WITH THIS CHEMICAL
                C
0029B8I               NFLOW=0
0029C0I          900  CONTINUE
0029C0I               CALL INPUT2(QO)
                C
                C     MASS PICK-UP
                C
0029D8I               GAM13=2.67894
0029E4I               SC=VISKIN/DSLOT
0029F6I               RE=(3.*QO*QSLOT*DSLOT)/(2.*FSSLOT*VISKIN*(XSLOT**2))
002A38I               E=1./3.
002A44I               COMASS=(3.*DIFFU*XSLOT)*CO*((3.*RE*SC)**E)/GAM13
                C
                C     FIND HOLD VOID VOLUME AND AIR CHANGES PER HOUR
                C
002A94I               VOL=VTOT
002AA0I               AIRCH=(3600.*QO)/VOL
002AB8I               WRITE(6,60) VOL,AIRCH
                C
                C     RECALL THAT NO MASS PICK-UP OCCURS IN THE MAIN VOID!
                C
002ADCI               SWEEP = COMASS*PICKUP
```

```
307  002AEEI         WRITE(6,90) SWEEP                                                    307
308  002B0CI         CONC=SWEEP/Q0                                                        308
309  002B1EI         WRITE(6,95) CONC                                                     309
310  002B3CI         NFLOW=NFLOW + 1                                                      310
311  002B4AI         IF (NFLOW.LT.NFLOWS) GCTO 900                                        311
312           C                                                                           312
313  002B60I         NCHEM=NCHEM + 1                                                      313
314  002B6EI         IF (NCHEM.LT.NCHEMS) GCTO 800                  314  002B6EI       IF (NCHEM.LT.NCHEMS) GOTO 800
315           C                                                                           315
316           C      WE WANT TO PLOT SLOT END PRESSURES FOR SLOTS N=NMIN AND N=NMAX.      316
317           C        THIS WILL BE DONE BY A SEPARATE PROGRAM USING PRESSURE VALUES      317
318           C        STOREO IN A OISK FILE.                                             318
319           C      THE CALL TO PPLOT IS TO BUILO THIS DISK FILE.                        319
320           C                                                                           320
321  002B84I         CALL PPLOT(XS,NMIN,NMAX,D3,DSL3,XL,XSLOT,FS,FSSLOT,XS0,YS0,          321
322                 &  QVOID,QSLOT,NSLOTS,NXSLOT)                                         322
323           C                                                                           323
324           C      LOOP BACK TO PICK UP ADDITIONAL CASES AS NEEOEO                      324
325           C                                                                           325
326  002BD4I         IF(NGEOMS.GT.NGEOM) GO TO 100                                        326
327           C                                                                           327
328  002BEAI         STOP                                                                 328
329  002BF2I         END                                                                  329

NO  ERRORS:F7D  R04-00     MAINPROG    .MAIN     06/24/81  08:12:44  TABLE SPACE:   7 KB
STATEMENT BUFFER:   20 LINES/1321 BYTES    STACK SPACE: 166 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
0000C0I         SUBROUTINE INTEG1(UB,UBO)
          C
          C     THIS ROUTINE CARRIES OUT INTEGRALS NEEDEO TO OEFINE THE VELOCITY
          C        IN THE BCTTOM OF A SLOT (OR THE MAIN VOID)
          C     THE VELOCITY CALCULATED IS FOR THE VOLUME FROM THE BOTTOM OF
          C        THE SLOT TO APPROXIMATELY ONE SLOT WIOTH UP. THE ASSUMPTION IS
          C        MADE THAT THE VELOCITY GOES ASYMTOTICALLY TO THAT FOUND FOR THE
          C        MAIN PART OF THE SLCT.
          C
          C     UB(J,K) = UB(Y,Z) IS THE AXIAL VELOCITY NEAR THE SLOT BOTTOM
          C     UBO(K) = 20.*UB(Z,Y=0.C5) APPRCXIMATES  UB'= PARTIAL UB PARTIAL Y
          C       AT Y=0
          C
          C     X  = COORDINATE ALONG SLOT LENGTH, DOES NOT FIGURE IN THIS CALCULATION
          C     Y  = OIMENSIONLESS COORDINATE UP FROM SLOT BOTTOM
          C     Z  =      "              "      ACROSS SLOT WIDTH
          C
          C     THE QUANTITY FORMED IS
          C
          C     UB(Y,Z) = (1-Z**2) - INTEGRAL (-1 TO 1) OF ZO*J(Y,Z,ZO) DZO
          C         FOR J SEE H. BAUM NOTES
          C
000004I         OIMENSION UB(10,11),UBO(11)
          C
          C     10 POINTS IN Y (UP) AND 10 IN Z (ACROSS) ARE TABULATED
          C       Y VARIES 0 TO 1 IN STEPS OF 0.1
          C       Z   "    0 " 1 "    "   "  0.1, Z=0. ON CENTER LINE
          C     20 POINTS ARE USEO IN THE INTEGRAL, ZO -1. TO 1.
          C
000004I         N=10
00001CI         N1=N+1
00002AI         OEL=1./(FLOAT(N))
00004EI         NO=20
000058I         OELO=2./(FLOAT(NO))
00007EI         PI=3.141592654
00008AI         PIHALF=1.570796327
000096I         TOLO=C.0001
0000A2I         Y=DEL
          C
          C     BEGIN INTEGRATION. TRAPOZOIDAL RULE USEO
          C
0000AEI         DO 800 J=1,N1
0000C2I         Z=0.
          C
0000CEI         DO 700 K=1,N1
0000E2I         SUM=0.
0000EEI         ZO=-1.
0000FAI         R=SIN(PIHALF*Z)*COSH(PIHALF*Y)
000160I         A=COS(PIHALF*Z)*SINH(PIHALF*Y)
          C
          C     THE TESTS WHICH FOLLOW ARE TO GET THE ARCTAN IN THE CORRECT SECTOR
```

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184   ***, SEE DOCUMENTATION PACKAGE, 04-101M99.

```
               C
   0001C4I            RO=-1.
   0001D0I            TEST=R-RO
   0001E2I            IF(TEST.LT.TOLO) GOTO 200
   0001FAI            TERM=ZO*(1./PI)*ATAN(A/(R-RO))
   000244I            GOTO 300
   00024AI      200   CONTINUE
   00024AI            IF(TEST.GT.-TOLO) GOTO 250
   00026AI            TERM=ZO*(1.-(1./PI)*ATAN(A/(RO-R)))
   00028EI            GOTO 300
   0002C4I      250   CONTINUE
   0002C4I            TERM=0.5*ZO
   0002D6I      300   CONTINUE
               C
               C      MAIN INTEGRATION LOOP
               C
   0002D6I            DO 600 I=1,NO
   0002EAI            ZO=ZO+DELO
   0002FCI            RO=SIN(PIHALF*ZO)
   00032AI            TEST=R-RO
   00033CI            IF(TEST.LT.TOLO) GOTO 400
   000354I            TERM1=ZO*(1./PI)*ATAN(A/(R-RO))
   0003A0I            GOTO 500
   0003A6I      400   CONTINUE
   0003A6I            IF(TEST.GT.-TOLO) GOTO 450
   0003C6I            TERM1=ZO*(1.-(1./PI)*ATAN(A/(RO-R)))
   00041AI            GOTO 500
   000420I      450   CONTINUE
   000420I            TERM1=0.5*ZO
   000432I      500   CONTINUE
   000432I            SUM=SUM+TERM+TERM1
   00044AI            TERM=TERM1
   000456I      600   CONTINUE
               C
   00046EI            SUM=SUM*DELO*0.5
   000486I            SUM=0.5*(1.-Z**2)-SUM
   0004AEI            IF(J.EQ.N1) GOTO 650
   0004C6I            UB(J,K)=SUM
   0004ECI            Z=Z+DEL
   0004FEI            GOTO 700
   000504I      650   CONTINUE
   000504I            UBO(K)=SUM*20.
   000524I            Z=Z+DEL
   000536I      700   CONTINUE
               C
   00054EI            Y=Y+DEL
   000560I            IF(J.EQ.N) Y=0.05
   00057EI      800   CONTINUE
               C
   000596I            RETURN
   00059CI            END
```

```
NO  ERRORS:F7D  R04-00     SUBROUTINE  INTEG1    06/24/81  08:13:46  TABLE SPACE:   3 KB
STATEMENT BUFFER:   20 LINES/1321 BYTES    STACK SPACE: 201 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
000000I          SUBROUTINE INTEG2(UB,UBO,W,WO)
           C
           C     THIS ROUTINE FORMS W, THE INDEFINATE INTEGRAL ON UB W.R.T. Z
           C        TRAPCZOIDAL RULE IS USED
           C
           C     WO IS THE ANALOGOUS INTEGRAL OF UBO
           C
           C     WO IS USED TO FORM THE STREAM FUNCTION AT THE BOTTOM
           C       OF A SLOT.
           C
000004I          DIMENSION UB(10,11),W(10,11),UBO(11),WO(11)
           C
000004I          N=10
000024I          N1=N+1
000032I          DEL=1./(FLOAT(N))
           C
000056I          DO 200 J=1,N
00006AI          W(J,1)=0.
           C
000084I          DO 100 K=2,N1
000098I          K1=K-1
0000A6I          W(J,K)=W(J,K1)+0.5*DEL*(UB(J,K)+UB(J,K1))
000134I      100 CONTINUE
           C
00014CI      200 CONTINUE
           C
000164I          WO(1) = 0.
           C
000174I          DO 300 K=2,N1
000188I          K1=K-1
000196I          WO(K)=WO(K1)+0.5*DEL*(UBO(K)+UBO(K1))
0001F4I      300 CONTINUE
           C
00020CI          RETURN
000212I          END
```

NO ERRORS:F7D R04-00 SUBROUTINE INTEG2 06/24/81 08:14:39 TABLE SPACE: 2 KB
STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 189 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184   ***, SEE DOCUMENTATION PACKAGE, 04-101M99.

```
000000I          SUBROUTINE INPUT(TK,DELT,XL,YB,H,D,XSLOT,YSLOT,NXSLOT,DSLOT,
               +  NSLOTS,XS,XSINK,YSINK,VTOT,VVOID,NCHEMS,SPACE)
           C
           C     INPUT DATA IN ORDER OF ENTRY WITH APPRCPIATE UNITS
           C
           C     DELT  = TEMPERATURE RISE FROM BOTTOM TO TOP OF VERTICLE SLOTS, DEG C
           C     XL    = LENGTH OF MAIN VOID, M
           C     YB    = WIDTH OF MAIN VOID, M
           C     H     = HEIGHT OF MAIN VOID AND INTERCONTAINER SLOTS, M
           C     XSLOT = LENGTH OF INTERCONTAINER SLOTS, M
           C     YSLOT = WIDTH OF INTERCONTAINER SLOTS, M
           C     SPACE = DISTANCE BETWEEN INTERCONTAINER SLOTS (CONTAINER WIDTH), M
           C     NXSLOT= NUMBER OF X POINTS FOR TABULATION CF SLOT VARIABLES
           C     NSLOTS= NUMBER OF INTERCONTAINER SLOTS (NUMBER OF CONTAINERS + OR - 1)
           C     XS    = X LOCATION OF SLOT INTERSECTION WITH MAIN VOID
           C     XSINK = X LOCATION OF MAIN VOID SOURCE (SINK), M
           C     YSINK = Y     "      "    "      "       "     M
           C     VTOT  = TOTAL VOLUME OF THE EMPTY HOLD
           C     VVOID = HOLD VOLUME - TOTAL VOLUME OF CONTAINERS LOADED
           C     NCHEMS= NUMBER OF SETS OF CHEMICAL DATA TO BE ENTERED
           C             DATA TO BE READ.
           C
000004I          DIMENSION XS(11)
           C
000004I      10  FORMAT (2F10.2)
000012I      20  FORMAT (5F10.2)
00001AI      30  FORMAT (3I10)
000020I      40  FORMAT(1H1,//,10X,'INPUT PARAMETERS:',/,12X,'TC    =',F5.2,
               &5X,'DELT =',F9.6,10X,'DEG C.',/,12X,'XL    =',F5.2,5X,'YB    =',
               & F5.2,5X,'ZH=',F5.2,' M',/,12X,'XSLOT=',F5.2,5X,'YSLOT=',F5.2,
               &  14X,'M',//,10X,I3,' INTERCONTAINER SLOTS SPACED=',F5.2,' M',
               &  //,10X,'NUMBER OF POINTS TABULATED:',
               &  /,12X,'NXSLOT=',I3)
000106I      80  FORMAT(10X,'*****',5X,'*****',5X,'*****',5X,'*****',
               &  5X,'*****',//)
000138I      81  FORMAT(10X,'NSLOTS TOO LARGE, MAX 30! INPUT NSLOTS =',I4)
000168I      83  FORMAT(10X,'NXSLOT TOO LARGE, MAX 11! INPUT NXSLOT =',I4)
000198I      90  FORMAT(10X,'VOID LENGTH IMPLIED BY INTERCONTAINER SPACING,',
               &  F5.2,/,10X,'IS GREATER THAN THE INPUT VOID LENGTH,',F5.2)
           C
0001FEI          IFLAG=0
00020CI          READ(5,10) DELT
           C
           C     TC, THE AMBIENT TEMPERATURE IS NOT INPUT HERE BUT SET AT A
           C         NOMINAL VALUE. IT WILL BE READ LATER, IN INPUT1, FOR
           C         SPECIFIC CALCULATIONS FOR VARIOUS CHEMICALS.
           C
00022CI          TC = 10.0
000238I          TOK=273.16
000244I          TK=TC+TOK
000256I          READ(5,20) XL,YB,H
```

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 ***, SEE DOCUMENTATION PACKAGE, 04-101M99.

```
00027CI              D=YB*0.5
00028EI              READ(5,20) XSLOT,YSLOT,SPACE
000234I              DSLOT=YSLOT*0.5
0002C6I              READ(5,30) NXSLOT,NSLOTS
0002E8I              IF (NSLOTS.GT.11) IFLAG=1
000300I              IF (NXSLOT.GT.30) IFLAG=3
000318I              IF (IFLAG.GT.0) GOTO 400
              C
00032EI              WRITE(6,40) TC,DELT,XL,YB,H,XSLOT,YSLOT,NSLOTS,SPACE,NXSLOT
000370I              N=(NSLOTS/2)*2
000390I              IF(N.EQ.NSLOTS) GOTO 200
0003A8I              N=NSLOTS/2
0003C2I              X=SPACE*(FLOAT(N))
              C
0003E4I              DO 150 I=1,NSLOTS
0003F8I              XS(I)=X
000412I              X=X-SPACE
000424I          150 CONTINUE
              C
00043CI              GOTO 300
              C
000442I          200 CONTINUE
000442I              N=(NSLOTS/2)-1
00045EI              X=(SPACE/2.)+SPACE*(FLOAT(N))
              C
00048EI              DO 250 I=1,NSLOTS
0004A2I              XS(I)=X
0004BCI              X=X-SPACE
0004CEI          250 CONTINUE
              C
0004E6I          300 CONTINUE
0004E6I              XSTEST=XS(1)-XS(NSLOTS)
00050AI              IF (XSTEST.GT.XL) GOTO 500
              C
000522I              READ(5,20) XSINK,YSINK
              C
000544I              READ(5,20) VTOT,VVOID
              C
000568I              READ(5,30) NCHEMS
              C
000588I              RETURN
              C
00058EI          400 CONTINUE
00058EI              WRITE(6,80)
0005A8I              IF (IFLAG.EQ.1) WRITE(6,81) NSLOTS
0005D8I              IF (IFLAG.EQ.3) WRITE(6,83) NXSLOT
000608I              STOP
              C
000610I          500 WRITE(6,90) XSTEST,XL
000634I              STOP
              C
```

```
103            C                                                                              103
104  00063CI          END                                                                     104

NO  ERRORS:F7D  R04-00     SUBROUTINE  INPUT     06/24/81  08:16:14  TABLE SPACE:   3 KB
STATEMENT BUFFER:   20 LINES/1321 BYTES    STACK SPACE: 126 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
000000I          SUBROUTINE SLOT1(NXSLOT,USLOT,N,XS,D3,DSL3,XL,XSLOT,FS
                & ,FSSLOT,XSD,YSD,QVOID,QSLOT,NSLOTS)
            C
            C    THIS IS FOR A SLOT OPEN AT ONE END ONLY
            C
            C    IT CALCULATES USLOT(I,N) = PARTIAL P/PARTIAL X FOR Y=0 AT
            C      X = X(I) FOR THE SLOT INTERSECTING THE MAIN VOID AT XS(N).
            C
            C    FOR EQUATIONS SEE H.BAUM NOTES: SECONDARY PASSAGE FORMULAE
            C        NOTATION FOLLOWS BAUM
            C    IN THE STATEMENT FUNCTION GRAD THE LAST VARIABLE IN THE LIST,
            C      K, WHEN SET = 1, INTEGRATES PRESSURES WITH A FIXED INTERVAL
            C      SIZE.  WHEN K = 0 THE INTEGRATION IS REPEATED WITH VARIOUS
            C      INTERVALS UNTIL A PRESET ACCURACY IS ACHIEVED.
            C
000004I          DIMENSION XS(11),USLOT(31,11)
            C
000004I          K=1
00001CI          NX1=NXSLOT+1
00002AI          DELX=1./NXSLOT
            C
00004OI          DO 100 I = 1,NX1
000054I          X = -0.5 + DELX*(I-1)
000070I          USLCT(I,N)=GRAD(X,XS,N,D3,DSL3,XL,XSLOT,FS,FSSLOT,XSD,YSD,
                &  QVOID,QSLCT,NSLOTS,K)
            C
0000F0I      100 CONTINUE
            C
000108I          RETURN
00010EI          END
```

NO ERRORS:F7D R04-00 SUBROUTINE SLOT1 06/24/81 08:17:14 TABLE SPACE: 2 KB
STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 108 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

```
000000I          FUNCTION GRAD(X,XS,N,D3,DSL3,XL,XSLOT,FS,FSSLOT,XSD,YSD,
               &  QVOID,QSLOT,NSLOTS,K)
            C
            C     WRITTEN BY: D. CORLEY, JUNE 1979
            C       REVISED, SEPTEMBER, 1979
            C
            C     CALC DP/DX=G(X)*INTEG 0 TO INF DP/DY*F(X,Y)*DY
            C     X = LOCATION ALONG THE SLOT, DIMENSIONLESS IN SLOT COORDINATES
            C     XS= LOCATION ALONG THE VOID,        "        "  VOID     "
            C     D3,DSL3 ARE HALF-WIDTHS OF VOID, SLOT CUBED
            C     XL,XSLOT ARE LENGTHS OF VOID, SLOT IN PHYSICAL COORDINATES
            C     FS,FSSLOT ARE SQRT(F(OMEGA)) FOR VOID, SLOT
            C     XSD,YSD ARE LOC OF SOURCE, DIMENSIONLESS IN VOID COORDINATES
            C     QVOID,QSLOT ARE SOURCE STRENGTH IN VOID, SLOT
            C     NSLOTS IS NUMBER OF SLOTS(GREATER THAN ONE)
            C     N  IS THE NUMBER OF THE SLOT WHERE THE VELOCITY IS DESIRED.
            C
000018I           DIMENSION XS(11)
            C
            C     THE FOLLOWING ARE FUNCTION DEFINITIONS
            C
000018I           G(X)=COS(PI*X)/SQRT(1.+SIN(PI*X))
000100I           F(X,Y)=SQRT(COSH(PI*Y)-1.)/(SIN(PI*X)+COSH(PI*Y))
000222I           YB(Y)=FSSLOT*XSLOT*Y/(FS*XL)
0002A0I           PL(Y)=QVOID*DSL3*FSSLOT*PRESS(XS,N,YB(Y),XSD,YSDS,
               &  QVOID,QSLOT,NSLOTS)/(QSLOT*D3*FS)
000388I           PI=4.*ATAN(1.)
            C
            C     IF XS(N) = XSD THE COMPUTATION WILL DIVERGE. THIS IS SUPPOSED
            C       TO HAVE BEEN AVOIDED BY A CHECK ON XS(N) AND XSD IN THE MAIN
            C       PROGRAM.
            C
000388I           IF(XS(N).EQ.XSD)GO TO 700
            C
            C     NOTE: THE AXIAL VELOCITY EXPRESSION HAS TROUBLE AT X = -0.5, SO
            C       WE EVALUATE THE VELOCITY NEAR, BUT NOT AT THE MOUTH OF THE
            C       SLOT.
            C
0003DEI           IF(X.LE.-.5)X=-.498
0003FCI           YSDS=YB(YSD)
            C
            C     IF K = 1 DO THE INTEGRAL ONCE WITH FIXED STEP SIZE
            C
000418I           IF(K.EQ.0) GO TO 400
00042EI           H2=0.
00043AI           H =0.02
000446I           TOL=0.0001
000452I           SUM=0.
00045EI           A1=PL(H2)
000478I           B1=F(X,H2)
000498I           A4=0.
```

```
0004A4I    200  H2=H2 + H
0004B6I         YD=YSDS
0004C2I         IF(H2.EQ.YSDS) YD=YSDS+C.001
0004E6I         A2=PL(H2)
000500I         B2=F(X,H2)
000520I         A3=A2-A1
000532I         B3=B2+B1
000544I         SUM=SUM + 0.5*A3*B3
           C
           C    SUM UNTIL PL(2) - PL(1) LESS THAN TOLERANCE (TOL) AND
           C      Y GREATER THAN 3.
           C
000562I         IF(A3-A4.LT.TOL.AND.H2.GE.3) GO TO 300
000592I         A1=A2
00059EI         B1=B2
0005AAI         A4=A3
0005B6I         GO TO 200
0005BAI    300  GRAD=SUM*G(X)
           C
           C    INTEGRAL FROM H2 TO INFINITY OF EXP(-PI*Y/2.)
           C
0005D8I         H=2.*EXP(-H2*PI/2.)/PI
000622I         GRAD = GRAD + H
000630I         RETURN
           C
           C    IF K = 0 ITERATE INTEGRAL UP TO 4 TIMES, EACH TIME
           C      CUTTING STEP SIZE IN HALF.
           C
000636I    400  CONTINUE
           C
           C    INTEGRAL FROM 0 TO 1 WITH 50 STEPS INITIALLY
           C
000636I         H1=0
000642I         H2=1
00064EI         H=.02
00065AI         SU=0
000666I         IFL=0
00066EI         TOL=.002
00067AI    401  SUM=0
000686I         ICT=0
00068EI    201  ICT=ICT+1
00069CI         TEST=SUM
0006A8I         H=H/2
0006BAI         NN=(H2-H1)/H+.5
0006DAI         SUM=0
0006E6I         IF(-YSDS.LT.-3.0) A1=0.
00070AI         IF(-YSDS.GE.-3.0) A1=PL(H1)
00073CI         B1=F(X,H1)
00075CI         DO 100 I=1,NN
000770I         HI=H1+I*H
00078AI         YTEST=YB(HI)-YSDS
```

```
0007AAI          IF(YTEST.LT.-3.0) A2=0.
0007C8I          IF(YTEST.GE.-3.0.AND.YTEST.LE.3.0) A2=PL(HI)
000808I          IF(YTEST.GT.3.0) A2=YB(HI)
000834I          B2=F(X,HI)
000854I          A3=A2-A1
000866I          33=B1+B2
000878I          SUM=SUM+.5*A3*33
000896I          A1=A2
0008A2I          B1=B2
0008AEI      100 CONTINUE
0008C6I          IF(ABS((SUM-TEST)/SUM).LE.TOL)GO TO 301
000906I          IF(ICT.LT.4)GO TO 201
00091AI          WRITE(6,1)ICT,H,TEST,SUM
000944I        1 FORMAT(1H ,'ERROR IN GRAD',I5,3(1PE12.4))
00096AI      301 GRAD=SUM*G(X)
000988I          SU=SU+SUM
00099AI          IF(IFL.EQ.1)GO TO 500
0009B0I          H1=1
0009BCI          H2=3
0009C8I          H=.1
0009D4I          IFL=1
0009DCI          GO TO 401
0009E0I      500 CONTINUE
0009E0I          GRAD=SU+.0057
            C
            C    .0057 IS THE INTEGRAL FROM 3 TO INF OF EXP(-PI*Y/2).
            C
0009F0I          RETURN
0009F6I      700 WRITE(6,7) N, XS(N)
000A34I        7 FORMAT(1H1,' ERROR, FOR N =',I4,' XS(N) = XSD =',1PE10.2)
000A68I          RETURN
000A6EI          END
```

NO ERRORS:F7D R04-00 FUNCTION GRAD 06/24/81 08:18:53 TABLE SPACE: 4 KB
STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 122 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

```
0000001I          FUNCTION PRESS(ZXS,N,ZY,ZXSD,ZYSDS,ZQVOID,ZQSLOT,NSLOTS)
          C
          C       WRITTEN BY D. CORLEY, MAY 1979
          C
          C       NOTATION FOLLOWS H. BAUM
          C
000018I           IMPLICIT DOUBLE PRECISION (A-H,O,Q-Y)
000018I           DOUBLE PRECISION PI,PXP,PXM
000018I           DIMENSION A(4),B(4),XS(11),ZXS(11)
          C
          C        NSLOTS SLOTS AND 1 MAIN VOID, (NSLOTS+1) IN ALL
          C        X,Y ARE DIMENSIONLESS POSITION OF POINT WHERE PRESSURE IS NEEDED
          C        XSD,YSDS ARE DIMENSIONLESS POSITION OF SOURCE
          C        QSLOT ARE VOL FLUX INTO INTERCONTAINER SLOTS
          C        QVOID IS VOL FLUX INTO MAIN VOID
          C        X GOES FROM -.5 TO +.5
          C        Y GOES FROM 0 TO (INFINITY)
          C        THE SLOTS ARE LOCATED AT POSITIONS XS
          C        WE ARE INTERESTED IN THE SLOT AT XS(N).
          C
000018I           Y     =DBLE(ZY)
0000DAI           XSD   =DBLE(ZXSD)
0000F6I           YSDS  =DBLE(ZYSDS)
000112I           QVOID=DBLE(ZQVOID)
00012EI           QSLOT=DBLE(ZQSLOT)
00014AI           DO 20 I=1,11
000152I           XS(I)=DBLE(ZXS(I))
000190I      20   CONTINUE
          C
0001A6I           X=XS(N)
          C       WRITE(6,10) X,N,Y,XSD,YSDS
          C10     FORMAT(5X,'IN PRESS X=',F7.3,' N=',I3,' Y=',F7.3,' XSD=',
          C      &  F5.3,' YSDS=',F5.3)
0001B8I           PI=4.00*DATAN(1.D0)
0001E8I           T1=NSLOTS*QSLOT/QVOID
000202I           IF(Y.GT.12.) GOTO 100
00021AI           EP=DEXP(PI*Y)
00024AI           EM=DEXP(-PI*Y)
000282I           EMB=DEXP(-PI*YSDS)
00028AI           EPB=DEXP(PI*YSDS)
          C
0002EAI           A1=DSIN(PI*X)*DCOSH(PI*Y)-DSIN(PI*XSD)*DCOSH(PI*YSDS)
00038CI           A2=DCOS(PI*X)*DSINH(PI*Y)
000420I           A3=DCOS(PI*XSD)*DSINH(PI*YSDS)
000484I           A4=A1*A1+(A2-A3)**2
0004AEI           A5=A1*A1+(A2+A3)**2
          C
000408I           G=DLOG(A4*A5)/(4.*PI)
          C       WRITE(6,1)EP,EM,EMB,EPB
          C    1  FORMAT(1H ,10(1PE10.2))
          C       WRITE(6,1)G,DELX,PI,T1,A1,A2,A3,A4,A5
```

```
000514I              A8=2-EMB
000526I              SUM=0
              C
              C      SUM CONTRIBUTION TO PRESSURE FROM EACH SLOT
              C
000532I              DO 40 I=1,NSLOTS
000546I              XN=XS(I)
000558I              PXP=PI*(X+XN)
000570I              PXM=PI*(X-XN)
000588I              A(1)=-EP*DCOS(PXP)
0005B2I              B(1)=EP*DSIN(PXP)
0005D2I              A(2)=EM*DCOS(PXM)
0005F2I              B(2)=EM*DSIN(PXM)
000612I              A(3)=-EM*DCOS(PXP)
00063AI              B(3)=EM*DSIN(PXP)
00065AI              A(4)=EP*DCOS(PXM)
00067AI              B(4)=EP*DSIN(PXM)
              C      WRITE(6,1)A,B
00069AI              SUM1=0
              C
              C      FIND THE FOUR TERMS WHICH, TOGETHER, GIVE THE PRESSURE
              C
0006A6I              DO 30 J=1,4
0006AEI              A1=A(J)*A(J)+B(J)*B(J)
0006E6I              A7=A(J)-1
0006FEI              A2=A7*A7+B(J)*B(J)
00072AI              A3=A(J)-EMB
000742I              A9=A3*A3+B(J)*B(J)
00076EI              A4=ABS(B(J))
00079EI              A5=EPB*EPB*A9
0007B6I              IF(A4.NE.0.D0)A11=A4*(DATAN2(A3,A4)-DATAN2(A(J),A4))
00082CI              IF(A4.EQ.0.D0)A11=0.D0
00084AI              AA1=1.+EPB*(.5*A(J)*DLOG(A9/A1)+A11)
00089EI              IF(A2.NE.0.D0)AA2=DLOG(A2/A9)-(.5*A(J)*EMB/A1)*DLOG(A2/A5)
                    .-.5*A8*DLOG(A2)
00095AI              IF(A4.NE.0.D0)AA3=-(EMB*A4/A1)*(DATAN2(A3,A4)-DATAN2(A7,A4))
0009D0I              IF(A4.EQ.0.D0)AA3=0.D0
0009EEI              IF(A2.EQ.0.D0)AA2=-DLOG(A9)+.5*EMB*DLOG(A5)
000A4EI              A6=AA1+AA2+AA3
              C      WRITE(6,1)A1,A2,A3,A4,A5,A6,A7,A8,A9
              C      WRITE(6,1)AA1,AA2,AA3,A11
000A66I           30 SUM1=SUM1+A6
000A8EI           40 SUM=SUM+SUM1
000AB8I              PRESS=SNGL((1+T1)*G+SUM*T1/(NSLOTS*2.*PI*A8))
000B20I              RETURN
000B26I          100 CONTINUE
000B26I              PRESS=SNGL(Y)
000B40I              RETURN
000B46I              END
```

NO ERRORS:F7D R04-00 FUNCTION PRESS 06/24/81 08:20:08 TABLE SPACE: 4 KB

```
STATEMENT BUFFER:   20 LINES/1321 BYTES    STACK SPACE: 223 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
DOUBLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
000000I          SUBROUTINE STRM1(NXSLOT,USLOT,WO,ZPSI,N,IMAX,XPSI,NMIN,NMAX)
          C
          C      THE STREAM FUNCTION FOR THE BOTTOM OF THE SLOT IS PSI(X,Z)
          C        DEFINED AT THE BEGINNING OF THIS PROGRAM AS PSI(I,K,N) IS
          C        THE VALUE OF PSI AT THE VALUES X(I), Z(K) FOR THE NTH SLOT.
          C        DETAILS SEE H. BAUM NOTES
          C
          C      WE WILL NEED VALUES OF (X,Z) FOR CONSTANT PSI TO CARRY OUT
          C        THE VAPOR PICK-UP INTEGRALS
          C
          C      THESE ARE STORED IN THE (TRIANGULAR) MATRIX ZPSI(I,L)
          C        LET L DEFINE A VALUE OF PSI = PSI(L,11,N)
          C        LET I DEFINE AN X AND SET
          C        ZPSI = Z(X) FOR THIS PARTICULAR PSI
          C
          C      FOR L = NX1 (CLOSED END), USLOT = 0. AND PSI = 0. FOR ALL Z
          C        ALSO FOR Z = 0. (CENTER-LINE, K=0), WO = 0. AND PSI = 0. FOR ALL X
          C
000004I          DIMENSION USLOT(31,11),WO(11),ZPSI(31,31),XPSI(31)
          C
000004I     10   FORMAT(1P5E16.6)
000014I     20   FORMAT(I10)
          C
000018I          PSI(I,K,N)=USLOT(I,N)*WO(K)
          C
000000I          DO 90 I=1,31
000008I          DO 80 J=1,31
0000E0I     80   ZPSI(I,J)=0.
00011CI     90   XPSI(I)=0.
          C
00014CI          NX1=NXSLOT+1
00015AI          DELX = 1./NXSLOT
          C
          C      LOAD ZPSI VALUES FOR THE (TRIVIAL) PSI = 0 STREAMLINE
          C
000170I          DO 100 I=1,NXSLOT
000184I          ZPSI(I,NX1)=0.0
0001AAI    100   CONTINUE
          C
0001C2I          ZPSI(NX1,NX1)=1.0
0001E8I          XPSI(NX1)=-0.5
          C
          C      FIND LOCATION OF MAXIMUM PSI. STREAMLINES ORIGONATE AT THE SLOT
          C        WALL TO THE RIGHT OF PSIMAX AND END EITHER AT X = -1/2 OR AT
          C        THE WALL BETWEEN PSIMAX AND X = -1/2.
          C
000202I          PSIMAX = 0.
00020EI          IMAX = NX1
          C
00021AI          DO 200 I=NXSLOT,1,-1
000226I          IF(PSIMAX.GE.PSI(I,11,N)) GO TO 200
```

```
00025EI          PSIMAX=PSI(I,11,N)
000288I          IMAX=I
000294I     200  CONTINUE
              C
              C    LOAD ZPSI VALUES FOR STREAMLINES WHICH LEAVE THE SLOT WALL
              C      BETWEEN X = 1/2 AND PSIMAX. WE TRACK STREAMLINES WHICH LEAVE
              C      THE SLOT WALL AT MESH POINTS, SO WE ARE INTERESTED IN INDICIES
              C      BETWEEN NSLOTS (I.E., FIRST POINT TO THE LEFT OF X = 1/2)
              C      AND LIM (POINT JUST TO THE RIGHT OF PSIMAX).
              C
0002AAI          LIM=IMAX+1
              C
0002B8I          DO 500 NN=NXSLOT,LIM,-1
0002D0I          PSICON=PSI(NN,11,N)
0002FCI          ZPSI(NN,NN)=1.0
000322I          XPSI(NN)=-0.5
00033CI          IM1=NN-1
              C
00034AI          DO 400 II=IM1,1,-1
000356I          KFLAG = 11
              C
00035EI          DO 300 K=1,10
000366I          KP1=K+1
000374I          KM1=K-1
000382I          TEST1=PSI(II,K,N)
0003A4I          TEST2=PSI(II,KP1,N)
              C
0003C8I          IF(PSICON.LT.TEST1) GO TO 300
0003E0I          IF(PSICON.GE.TEST2) GO TO 300
0003F8I          ZPSI(II,NN)=0.1*(FLOAT(KM1)+(PSICON-TEST1)/(TEST2-TEST1))
000452I          KFLAG=K
00045EI          GO TO 301
000464I     300  CONTINUE
00047AI     301  CONTINUE
              C
00047AI          IF(KFLAG.LT.11) GO TO 400
              C
              C    KFLAG .GE. 11 IMPLIES NO HIT IN THE INTERPOLATION SEARCH.
              C      STREAMLINE HAS RETURNED TO THE WALL BETWEEN THIS X INDEX
              C      AND THE PREVIOUS ONE.  INTERPOLATE TO FIND THE X LOCATION
              C      OF THE STREAMLINE - WALL INTERSECTION.
              C
000490I          IIP1=II + 1
00049EI          IIM1=II - 1
0004ACI          TEST1=PSI(II,11,N)
0004D8I          TEST2=PSI(IIP1,11,N)
000504I          XPSI(NN)=-0.5+DELX*(FLOAT(IIM1)+(PSICON-TEST1)/(TEST2-TEST1))
000558I          GO TO 401
00055EI     400  CONTINUE
000574I     401  CONTINUE
              C
```

```
000574I     500  CONTINUE
               C
00058CI          ZPSI(IMAX,IMAX)=1.0
0005B2I          XPSI(IMAX)=-0.5+OELX*(IMAX-1)
               C
               C IF N=NMIN OR NMAX WE WANT TO SAVE ZPSI ANO XPSI FOR LATER PLOTS
               C   WRITE ZPSI(I,N) ANO XPSI(I) TO OISK FILE
               C
00050CI          IF(N.EQ.NMIN) GO TO 60C
0005F4I          IF(N.EQ.NMAX) GO TC 600
00060CI          GO TO 1001
               C
000612I     600  CONTINUE
000612I          WRITE(7,20) IMAX
000630I          IMIN=1
000638I          IMX=5
000640I     700  OO 800 J=1,NX1
000654I          WRITE(7,10) (ZPSI(I,J),I=IMIN,IMX)
0006E8I     800  CONTINUE
000700I          IF(IMX.GE.NX1) GO TO 9C0
000718I          IMIN=IMIN+5
000726I          IMX=IMX+5
000734I          IF(IMX.GT.NX1) IMX=NX1
000752I          GO TO 700
000756I     900  CONTINUE
               C
000756I          DO 1000 J=1,NX1
00076AI          WRITE(7,10) XPSI(J)
0007A4I    1000  CONTINUE
0007BCI    1001  CONTINUE
               C
00078CI          RETURN
0007C2I          END
```

NO ERRORS:F7D R04-00 SUBROUTINE STRM1 06/24/81 08:21:38 TABLE SPACE: 3 KB
STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 167 WOROS
SINGLE PRECISION FLOATING PT SUPPORT REQUIREO FOR EXECUTION

FORTRAN VIIC: LICENSEO RESTRICTED RIGHTS AS STATEO IN LICENSE L-0184 ***, SEE DOCUMENTATION PACKAGE, 04-101M99.

```
000000I          SUBROUTINE PICUP1(NXSLOT,ZPSI,XPSI,USLOT,WO,UBO,TOTAL,N,IMAX)
            C
            C    THIS FORMS THE INTEGRAL ALONG LINES OF CONSTANT PSI OF
            C      OL/Q
            C      WHERE Q**2 = (UBO*USLOT(I,N))**2 + (WO*UP)**2
            C        UP = FUNCTION DEFINEO BELOW, IT IS THE OERIVATIVE OF USLOT
            C             WITH RESPECT TO X EVALUATEO AT Y = 0.
            C           NOTE THAT UP IS SINGULAR FOR X = -0.5
            C           THIS WILL MAKE THE INTEGRANO, 1/Q = 0. SO THERE
            C           WILL BE NO CONTRIBUTION TO THE INTEGRAL FOR THIS
            C           X VALUE.
            C        RECALL THAT WO = 0. FOR Z = 0.
            C                    UBO= 0. FOR Z = 1.
            C    THE INTEGRALS ARE RETURNED IN SUM(J)
            C    REF: H.BAUM NOTES: STRONG SLOT, PAGES 42,46,47 ANO
            C      UNNUMBEREO SHEET. NOTE THAT I1 OF THIS SHEET IS NOT
            C      INCLUDEO IN THIS VERSION.
            C
            C    WE HAVE ZPSI(I,K) = Z FOR FIXED PSI, X IMPLIEO FROM I ANO PSI FROM K
            C
            C    WE WILL FORM INTEGRALS FOR THE STREAMLINES ORIGONATING AT MESH POINTS
            C      BEGINNING AT THE BACK OF THE SLOT ANO WORKING TOWARD TO OPEN END
            C      STOPPING EITHER AT THE MESH POINT WHERE THE STREAM FUNCTION IS A
            C      MAXIMUM OR AT THE END OF THE SLOT.  IN THE LATTER CASE, NOTE THAT
            C      THERE WOULD BE ONLY ONE POINT FOR ZPSI(I,1) ANO THIS INTEGRAL
            C      WOULD BE 0 BECAUSE THE PATH LENGTH WOULOBE 0, I.E. SUM(1) = 0.
            C
000004I          DIMENSION ZPSI(31,31),USLOT(31,11),WO(11),UBO(11),SUM(30)
               &  ,TOTAL(11),XPSI(31)
            C
000004I          PSI(I,K,N) = USLOT(I,N)*WO(K)
000144I          UP(X) = SQRT(2./(1+SIN(PI*X)))
            C
0001F0I          PI = 3.141592654
0001FCI          NX1=NXSLOT + 1
00020AI          OX = 1./FLOAT(NXSLOT)
00022EI          LIM=IMAX+1
            C
00023CI          OO 100 J=1,NX1
000250I          SUM(J) = 0.
000262I      100 CONTINUE
            C
            C    START INTEGRAL AT SLOT WALL, Z= 1., ANO INTEGRATE
            C      TOWARO X = -0.5
            C    NOTE: THE STAGNATION STREAMLINE, J = NX1, IS TREATEO SPECIALLY
            C          INDEX J (BELOW) REFERS TO THE STREAMLINE
            C          INDEX I REFERS TO THE X LOCATION OF THE INTEGRAND TERM
            C            BEING FORMED.
            C
00027AI          SUM(IMAX)=0.
            C
```

```
00028CI          DO 300 J=LIM,NXSLOT
0002A4I          JM1=J-1
0002B2I          W=WO(11)
0002C2I          X=DX*JM1-0.5
0002DCI          Q=ABS(W*UP(X))
00031AI          TERM1 = 1./Q
           C
           C     FORM THE NEXT INTEGRAND VALUE ALONG THE STREAMLINE
           C
00032CI          IFLAG=0
           C
000334I          DO 200 I=JM1,1,-1
000340I          IM1=I-1
00034EI          IP1=I+1
00035CI          X=DX*IM1-0.5
000376I          IF(X.GE.XPSI(J)) GO TO 180
           C
           C     FAILURE OF THE ABOVE TEST TELL US THAT
           C       STREAMLINE HAS REACHED THE WALL TO THE RIGHT OF THE
           C       CURRENT POINT.  IN THIS CASE THE TERM BECOMES
           C
00039CI          W=WO(11)
0003ACI          Q=ABS(W*UP(XPSI(J)))
000402I          TERM2=1./Q
000414I          DZ=1.0-ZPSI(IP1,J)
000440I          DEL=XPSI(J)-(-0.5+DX*I)
000470I          DL=SQRT(DEL**2+DZ**2)
0004BAI          SUM(J)=SUM(J) + (TERM1 + TERM2)*DL*0.5
0004EAI          GO TO 201
           C
0004F0I     180  CONTINUE
0004F0I          IF(I.GT.1) GO TO 190
           C
           C     BECAUSE THE INTEGRAND VANISHES AT X = -0.5 THE LAST CONTRIBUTION
           C       TO THE INTEGRAL IS AS FOLLOWS
           C
000506I          DZ=ZPSI(2,J) - ZPSI(1,J)
000540I          DL=SQRT(DX**2 + DZ**2)
00058AI          SUM(J)=SUM(J) + TERM1*DL*0.5
0005B4I          GO TO 200
           C
0005BAI     190  CONTINUE
0005BAI          ZI=ZPSI(I,J)*10.
0005E6I          IZ =IFIX(ZI)
000602I          IZP1=IZ+1
000610I          IZP2=IZ+2
00061EI          ZI=FLOAT(IZ)*0.1
000640I          F=(ZPSI(I,J)-ZI)*10.
000672I          U=UBO(IZP1)+F*(UBO(IZP2)-UBO(IZP1))
0006BAI          W=WC(IZP1) +F*(WO(IZP2) -WC(IZP1))
000702I          Q=SQRT((U*USLOT(I,N))**2 + (W*UP(X))**2)
```

```
000786I          TERM2 = 1./Q
000798I          DZ =ZPSI(IP1,J)-ZPSI(I,J)
0007DEI          DL =SQRT(DX**2 + DZ**2)
00082AI          SUM(J)=SUM(J) + (TERM1 + TERM2)*DL*0.5
00085AI          TERM1=TERM2
000866I     200  CONTINUE
00087CI     201  CONTINUE
           C
00087CI     300  CONTINUE
           C
           C     STAGNATION STREAMLIUNE INTEGRAL
           C
000894I          J=NX1
0008A0I          SUM(J)=0.
0008B2I          DZ=0.1
0008BEI          X=0.5
0008CAI          Q=ABS(WO(11)*UP(X))
00090AI          TERM1=1./Q
           C
00091CI          DO 400 K=10,2,-1
000924I          Q=SQRT((UBO(K)*USLOT(NX1,N))**2+(WO(K)*UP(X))**2)
0009C6I          TERM2=1./Q
0009D8I          SUM(J)=SUM(J)+(TERM1+TERM2)*DZ*0.5
000A08I          TERM1=TERM2
000A14I     400  CONTINUE
           C
000A2AI          DL=SQRT(DX**2+DZ**2)
000A76I          I=NXSLOT
000A82I          Q=ABS(UBO(1)*USLOT(I,N))
000ACEI          TERM2=1./Q
000AE0I          SUM(J)=SUM(J)+(TERM1+TERM2)*DL*0.5
000B10I          TERM1=TERM2
000B1CI          II=NXSLOT - 1
           C
000B2AI          DO 450 I=II,1,-1
000B36I          Q=ABS(UBO(1)*USLOT(I,N))
000B82I          TERM2=1./Q
000B94I          SUM(J)=SUM(J)+(TERM1+TERM2)*DX*0.5
000BC4I          TERM1=TERM2
000BD0I     450  CONTINUE
           C
           C     THE TOTAL MASS PICK-UP IS TWICE THE INTEGRAL OF SUM(K)
           C       TWICE BECAUSE WE INTEGRATE THE SYMETRIC FUNCTION FROM
           C       THE CENTER-LINE TO ONE EDGE.
           C
000BE6I          E=2./3.
000BF2I          TOTAL(N)=0.
000C0CI          PSI1=PSI(NX1,11,N)
000C38I          TERM1=(SUM(NX1))**E
           C
000C56I          DO 500 J=NXSLOT,IMAX,-1
```

```
000C6EI          PSI2=PSI(J,11,N)
000C98I          OPSI=PSI2-PSI1
000CAAI          TERM2=(SUM(J))**2
000CC8I          TOTAL(N)=TOTAL(N)+(TERM1+TERM2)*OPSI
000002I          PSI1=PSI2
           C     WRITE(6,1000) TOTAL(N),TERM1,TERM2,OPSI
00000EI          TERM1=TERM2
00001AI      500 CONTINUE
           C1000 FORMAT(10X,'TOTAL =',1P4E15.6)
           C
000032I          RETURN
           C
000038I          END

NO  ERRORS:F70  R04-00     SUBROUTINE  PICUP1    06/24/81  08:23:08  TABLE SPACE:   4 KB
STATEMENT BUFFER:   20 LINES/1321 BYTES    STACK SPACE: 214 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
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FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 ***, SEE DOCUMENTATION PACKAGE, 04-101M99.

```
000000I          SUBROUTINE PRINT1(XSLOT,NXSLOT,USLOT,XS,NSLOTS,XL,
                & WO,TOTAL)
            C
            C    THIS PRINTS RESULTS FOR THE INTERCONTAINER SLOTS
            C
000004I          DIMENSION USLOT(31,11),XS(11),
                & WO(11),TOTAL(11)
            C
000004I          DATA BLANK/'.'/
            C
000004I          PSI(I,K,N)=USLOT(I,N)*WO(K)
            C
0000C8I      5   FORMAT(1H1,///,10X,'INTERCONTAINER SLOT RESULTS')
0000F0I     20   FORMAT(///,10X,'INTERCONTAINER SLOT VELOCITY - U')
00011AI     40   FORMAT(F9.4,2X,1P11E10.3)
00012AI     50   FORMAT(///,4X,'X\LOC= ',1P11E10.2)
000142I     55   FORMAT(1X,A1)
000148I     60   FORMAT(///,10X,'INTERCONTAINER SLOT BOTTOM STREAM FUNCTION',
                & //,10X,'FOR SLOT AT LOCATION X =',F6.2)
00019CI     70   FORMAT(///,4X,'X\Z=  ',1P11E10.2)
0001B4I     90   FORMAT(///,10X,'DIMENSIONLESS MASS PICK-UP',//,
                & 10X,'SLOT LOCATION   MASS PICK-UP',//)
0001FCI     91   FORMAT(F15.2,7X,1PE15.5)
            C
00020AI          WRITE(6,5)
            C
000224I          DELX=1./NXSLOT
00023AI          NX1=NXSLOT+1
000248I          XINC=DELX * XSLOT
00025AI          X=-0.5*XSLOT-XINC
00027AI          WRITE(6,20)
000294I          WRITE(6,50) (XL*XS(I),I=1,NSLOTS)
000320I          WRITE(6,55) BLANK
000340I          DO 220 I=1,NX1
000354I          X=X+XINC
000366I          WRITE(6,40) X,(USLOT(I,J),J=1,NSLOTS)
0003F8I    220   CONTINUE
            C
000410I          DO 600 N=1,NSLOTS
000424I          X1=XS(N)*XL
000444I          X=-0.5*XSLOT-XINC
000464I          WRITE(6,60) X1
000484I          WRITE(6,70) (0.1*I,I=0,10)
0004F6I          WRITE(6,55) BLANK
000514I          DO 500 I=1,NX1
000528I          X=X+XINC
00053AI          WRITE(6,40) X,(PSI(I,K,N),K=1,11)
0005BEI    500   CONTINUE
            C
0005D6I    600   CONTINUE
            C
```

```
FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184       ***, SEE DOCUMENTATION PACKAGE, 04-101M99.

0005EEI         WRITE(6,90)
000608I         DO 700 I=1,NSLOTS
00061CI         WRITE(6,91) XS(I),TOTAL(I)
000674I    700  CONTINUE
            C
00068CI         RETURN
000692I         END

NO  ERRORS:F7D  R04-00     SUBROUTINE  PRINT1    06/24/81  08:27:25  TABLE SPACE:   3 KB
STATEMENT BUFFER:   20 LINES/1321 BYTES     STACK SPACE: 136 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
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```
000000I          SUBROUTINE PRINT(UB,UBO,W,WO)
            C
            C      THIS PRINTS RESULTS FOR THE MAIN VOID AND THE
            C        LOCATION INDEPENDENT VARIABLES UB,UBO,W, AND WO
            C
000004I          DIMENSION UB(10,11),UBO(11),W(10,11),WO(11),ZZ(11)
            C
000004I          DATA BLANK/'.'/
            C
000004I       5  FORMAT(1H1,///,10X,'GEOMETRY INDEPENDENT RESULTS')
000032I      18  FORMAT(///,10X,'FIELD OF UB')
000046I      19  FORMAT(///,10X,'FIELD OF UBO')
00005CI      20  FORMAT(F9.4,2X,1P11E10.2)
00006CI      50  FORMAT(///,4X,'Y\Z=    ',1P11E10.2)
000084I      55  FORMAT(1X,A1)
00008AI      60  FORMAT(////)
000090I      70  FORMAT(///,10X,'FIELD OF W = INDEFINATE Z INTEGRAL OF UB')
0000C2I      80  FORMAT(///,10X,'FIELD OF WO = INDEFINATE Z INTEGRAL OF UBO')
            C
0000F6I          WRITE(6,5)
            C
000154I          DO 550 I=1,11
00015CI          ZZ(I)=0.1*(I-1)
000178I     550  CONTINUE
            C
00018EI          WRITE(6,18)
0001A8I          WRITE(6,50) (ZZ(I),I=1,11)
00021AI          WRITE(6,55) BLANK
            C
000238I          DO 600 I=1,10
000240I          Y=0.1*I
000254I          WRITE(6,20) Y,(UB(I,J),J=1,11)
0002DAI     600  CONTINUE
            C
0002F0I          Y=0.05
0002FCI          WRITE(6,19)
000318I          WRITE(6,50) (ZZ(I),I=1,11)
00038AI          WRITE(6,55) BLANK
0003A8I          WRITE(6,20) Y,(UBO(I),I=1,11)
000422I          WRITE(6,70)
00043CI          WRITE(6,50) (ZZ(I),I=1,11)
0004AEI          WRITE(6,55) BLANK
            C
0004CCI          DO 700 I=1,10
0004D4I          Y=0.1*I
0004E8I          WRITE(6,20) Y,(W(I,J),J=1,11)
00056EI     700  CONTINUE
            C
000584I          WRITE(6,80)
0005A0I          WRITE(6,50) (ZZ(I),I=1,11)
000612I          WRITE(6,55) BLANK
```

```
 52  000630I          Y=0.05                                                          52
 53  00063CI          WRITE(6,20) Y,(WO(J),J=1,11)                                    53
 54             C                                                                     54
 55  000686I          WRITE(6,60)                                                     55
 56             C                                                                     56
 57  0006D0I          RETURN                                                          57
 58  0006D6I          END                                                             58

NO  ERRORS:F7D  R04-00     SUBROUTINE  PRINT     06/24/81  08:28:26  TABLE SPACE:   2 KB
STATEMENT BUFFER:   20 LINES/1321 BYTES    STACK SPACE: 133 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 ***, SEE DOCUMENTATION PACKAGE, 04-101M99.

```
000000I           SUBROUTINE INPUT1(DIFFU,CO,TK,NFLOWS)
            C
            C     INPUT DATA FOR EACH CASE IN ORDER OF ENTRY
            C     REPEAT FOR EACH CASE UP TO NCHEMS
            C
            C     CASE TITLE, 80 ALPHAMERIC CHARACTERS MAX
            C     DIFFU = MASS DIFFUSIVITY OF SPILL VAPOR IN AIR AT 0 DEG C.
            C                CM**2/SEC
            C     WM    = MOLECULAR WEIGHT OF SPILL CHEMICAL
            C     B     = MATERIAL DEPENDENT EMPIRICAL CONSTANT, B OF ANTON'S FORMULA, DEG K
            C     T1    = TEMPERATURE, DEG C, AT WHICH SPILL CHEMICAL HAS A VAPOR
            C             PRESSURE OF 1 ATMOS.
            C     T2    = REFERENCE TEMPERATURE, C OF ANTON'S FORMULA
            C     TC    = AMBIENT TEMPERATURE, DEGREES C
            C     NFLOWS= NUMBER OF VENTELATION FLOW RATES TO BE INCLUDED.
            C
000004I           DIMENSION TITLE(80)
            C
000004I      5    FORMAT(80A1)
000010I      8    FORMAT(///,10X,80A1)
00001CI     10    FORMAT(6F10.2)
000024I     20    FORMAT(I10)
000028I     30    FORMAT(//,10X,'TC =',F5.1,' DEC C',10X,'CO =',F7.2,' GM/M**3',
                 +  10X,'P =',F6.2,' MM HG')
            C
000066I           READ(5,5) TITLE
0001CCI           WRITE(6,8) TITLE
0001F0I           TOK = 273.16
0001FCI           READ(5,10) DIFFU,WM,B,T1,T2,TC
            C
000230I           TKA = T2 + TC
000242I           TKA1= T2 + T1
000254I           T = TC + TOK
000266I           C=1.0E-4
000272I           E=1.81
00027EI           DIFFU=DIFFU*C*(T/TOK)**E
000286I           CO = 44.613*WM*(TOK/T)*EXP(B*(TKA-TKA1)/(TKA1*TKA))
000314I           PP =                760.*EXP(B*(TKA-TKA1)/(TKA1*TKA))
00035CI           WRITE(6,30) TC,CO,PP
            C
000384I           READ(5,20) NFLOWS
            C
0003A4I           RETURN
            C
0003AAI           END
```

NO ERRORS:F7D R04-00 SUBROUTINE INPUT1 06/24/81 08:29:30 TABLE SPACE: 2 KB
STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 124 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

```
0000001             SUBROUTINE INPUT2(QO)
              C
              C     QO = MAIN VOID SINK STRENGTH, M**3/SEC
              C
000004I        10   FORMAT (F10.2)
              C
000010I             READ(5,10) QO
000030I             RETURN
000036I             END
```

NO ERRORS:F7D R04-00   SUBROUTINE INPUT2   06/24/81 08:30:25 TABLE SPACE: 1 KB
STATEMENT BUFFER: 20 LINES/1321 BYTES   STACK SPACE: 47 WORDS

FORTRAN VIID: LICENSEO RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 ***, SEE DOCUMENTATION PACKAGE, 04-101M99.

```
000000I          SUBROUTINE PPLCT(XS,NMIN,NMAX,D3,DSL3,XL,XSLOT,FS,FSSLOT,XSO,
               &  YSD,QVOIO,QSLOT,NSLOTS,NXSLOT)
            C
            C    WE WANT TO PLOT SLOT END PRESSURES FOR SLOTS N=NMIN ANO N=NMAX.
            C      THIS WILL BE OONE BY A SEPARATE PROGRAM USING PRESSURE VALUES
            C      STOREO IN A OISK FILE.
            C    THE CALL TO PPLOT IS TO BUILO THIS OISK FILE.
            C
000004I          OIMENSION XS(11)
            C
000004I      10  FORMAT(1P3E15.6)
000014I      20  FORMAT(5I5,1P4E15.6)
            C
000022I          YB(Y)=FSSLOT*XSLOT*Y/(FS*XL)
0000A4I          PL(Y)=QVOIO*DSL3*FSSLOT*PRESS(XS,N,YB(Y),XSO,YSDS,
               &  QVOID,QSLOT,NSLOTS)/(QSLOT*D3*FS)
            C
            C    PUT HEADER INFORMATION ON PRESSURE PLOT FILE
            C
00018CI          NYS=100
000196I          NYSP1=NYS+1
0001A4I          WRITE(8,20) NYS,NXSLOT,NSLOTS,NMIN,NMAX,XS(NMIN),XS(NMAX),
               &  XSO,YSD
            C
000218I          Y=0
000224I          DELY=1./FLOAT(NYS)
00024AI          YSDS=YB(YSD)
            C
000264I          OC 400 I=1,NYSP1
000278I          TEST=Y+OELY
00028AI          IF(Y.LT.YSO.AND.TEST.GE.YSO) GC TO 450
0002B4I          N=NMIN
0002C0I          PMIN=PL(Y)
00020CI          N=NMAX
0002E8I          PMAX=PL(Y)
000304I          WRITE(8,10) Y,PMIN,PMAX
00032CI          GO TO 490
            C
000332I     450  CONTINUE
000332I          TEST1=YSD-0.001
000344I          TEST2=YSD+0.001
000356I          N=NMIN
000362I          PMIN=PL(TEST1)
00037CI          N=NMAX
000388I          PMAX=PL(TEST1)
0003A4I          WRITE(8,10) TEST1,PMIN,PMAX
0003CCI          N=NMIN
0003D8I          PMIN=PL(TEST2)
0003F4I          N=NMAX
000400I          PMAX=PL(TEST2)
00041CI          WRITE(8,10) TEST2,PMIN,PMAX
```

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 ***, SEE DOCUMENTATION PACKAGE, 04-101M99.

```
                C
000444I   490  CONTINUE
000444I        Y=Y+DELY
000456I   400  CONTINUE
00046EI        RETURN
000474I        END
```

```
NO  ERRORS:F7D  R04-00     SUBROUTINE  PPLOT     06/24/81  08:31:23  TABLE SPACE:   2 KB
STATEMENT BUFFER:   20 LINES/1321 BYTES    STACK SPACE: 110 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

FORTRAN VIID: LICENSED RESTRICTED RIGHTS AS STATED IN LICENSE L-0184 ***, SEE DOCUMENTATION PACKAGE, 04-101M99.

```
000000I          FUNCTION PRESS(XS,N,Y,XSD,YSDS,QVOID,QSLOT,NSLOTS)
           C
           C     WRITTEN BY D. CORLEY, MAY 1979
           C
           C     NOTATION FOLLOWS H. BAUM
           C
000018I          DIMENSION A(4),B(4),XS(11)
           C
           C      NSLOTS SLOTS AND 1 MAIN VOID, (NSLOTS+1) IN ALL
           C      X,Y ARE DIMENSIONLESS POSITION OF POINT WHERE PRESSURE IS NEEDED
           C      XSD,YSDS ARE DIMENSIONLESS POSITION OF SOURCE
           C      QSLOT ARE VOL FLUX INTO INTERCONTAINER SLOTS
           C      QVOID IS VOL FLUX INTO MAIN VOID
           C      X GOES FROM -.5 TO +.5
           C      Y GOES FROM 0 TO (INFINITY)
           C      THE SLOTS ARE LOCATED AT POSITIONS XS
           C      WE ARE INTERESTED IN THE SLOT AT XS(N).
           C
000018I          X=XS(N)
           C     WRITE(6,10) X,N,Y,XSD,YSDS
           C10   FORMAT(5X,'IN PRESS X=',F7.3,' N=',I3,' Y=',F7.3,' XSD=',
           C    &  F5.3,' YSDS=',F5.3)
00005EI          PI=4.*ATAN(1.)
00008CI          T1=NSLOTS*QSLOT/QVOID
0000A6I          IF(Y.GT.12.) GOTO 100
0000BEI          EP=EXP(PI*Y)
0000EEI          EM=EXP(-PI*Y)
000126I          EMB=EXP(-PI*YSDS)
00015EI          EPB=EXP(PI*YSDS)
           C
00018EI          A1=SIN(PI*X)*COSH(PI*Y)-SIN(PI*XSD)*COSH(PI*YSDS)
000260I          A2=COS(PI*X)*SINH(PI*Y)
0002C4I          A3=COS(PI*XSD)*SINH(PI*YSDS)
000328I          A4=A1*A1+(A2-A3)**2
000352I          A5=A1*A1+(A2+A3)**2
           C
00037CI          G=ALOG(A4*A5)/(4.*PI)
           C     WRITE(6,1)EP,EM,EMB,EPB
000388I        1 FORMAT(1H ,10(1PE10.2))
           C     WRITE(6,1)G,DELX,PI,T1,A1,A2,A3,A4,A5
0003CCI          A8=2-EMB
0003DEI          SUM=0
           C
           C     SUM CONTRIBUTION TO PRESSURE FROM EACH SLOT
           C
0003EAI          DO 40 I=1,NSLOTS
0003FEI          XN=XS(I)
000418I          PXP=PI*(X+XN)
000430I          PXM=PI*(X-XN)
000448I          A(1)=-EP*COS(PXP)
000472I          B(1)=EP*SIN(PXP)
```

```
000492I          A(2)=EM*COS(PXM)
0004B2I          B(2)=EM*SIN(PXM)
0004D2I          A(3)=-EM*COS(PXP)
0004FAI          B(3)=EM*SIN(PXP)
00051AI          A(4)=EP*COS(PXM)
00053AI          B(4)=EP*SIN(PXM)
         C       WRITE(6,1)A,B
00055AI          SUM1=0
         C
         C       FIND THE FOUR TERMS WHICH, TOGETHER, GIVE THE PRESSURE
         C
000566I          DO 30 J=1,4
00056EI          A1=A(J)*A(J)+B(J)*B(J)
0005A6I          A7=A(J)-1
0005BEI          A2=A7*A7+B(J)*B(J)
0005EAI          A3=A(J)-EMB
000602I          A9=A3*A3+B(J)*B(J)
00062EI          A4=ABS(B(J))
00065EI          A5=EPB*EPB*A9
000676I          IF(A4.NE.0.)A11=A4*(ATAN2(A3,A4)-ATAN2(A(J),A4))
0006ECI          IF(A4.EQ.0.)A11=0.
00070AI          AA1=1.+EPB*(.5*A(J)*ALOG(A9/A1)+A11)
00075EI          IF(A2.NE.0.)AA2=ALOG(A2/A9)-(.5*A(J)*EMB/A1)*ALOG(A2/A5)
                .-.5*A8*ALOG(A2)
00081AI          IF(A4.NE.0.)AA3=-(EMB*A4/A1)*(ATAN2(A3,A4)-ATAN2(A7,A4))
000890I          IF(A4.EQ.0.)AA3=0.
0008AEI          IF(A2.EQ.0.)AA2=-ALOG(A9)+.5*EMB*ALOG(A5)
00090EI          A6=AA1+AA2+AA3
         C       WRITE(6,1)A1,A2,A3,A4,A5,A6,A7,A8,A9
         C       WRITE(6,1)AA1,AA2,AA3,A11
000926I       30 SUM1=SUM1+A6
00094EI       40 SUM=SUM+SUM1
000978I          PRESS=(1+T1)*G+SUM*T1/(NSLOTS*2.*PI*A8)
0009B8I          RETURN
0009BEI      100 CONTINUE
0009BEI          PRESS=Y
0009C8I          RETURN
0009CEI          END
WARNING # 301 ***********************************************************************
          >>> UNREFERENCED LABEL                                                  <<<
              SYMBOL/LABEL =  1

NO  ERRORS:F7D  R04-00     FUNCTION    PRESS     06/24/81  08:32:35  TABLE SPACE:   3 KB
STATEMENT BUFFER:   20 LINES/1321 BYTES    STACK SPACE: 223 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

```
                $BATCH
                C      PROGRAM TO READ DATA FROM DISK FILES AND PREPARE PLOTS
                C
                C      TWO SETS OF PLOTS ARE DRAWN
                C        SLOT END PRESSURE VERSUS HEIGHT FOR TWO SLOTS:
                C          1) THE SLOT FURTHEST FROM THE SUCTION
                C          2) THE SLOT CLOSEST TO THE SUCTION
                C        THESE ARE DRAWN BY SUBROUTINE PLOTP
                C
                C        SLOT BOTTOM STREAMLINES.  FOR THESE THE TRANSVERSE
                C          SCALE IS EXAGERATED RELATIVE TO THE LENGTH SCALE
                C          BY A FACTOR OF 10.
                C        THESE ARE DRAWN BY SUBROUTINE PLOTST
                C
    000000I            DIMENSION Y(103),P1(103),P2(103),ZPSI(31,31,2),XPSI(31,2)
                      &  ,IMAX(2)
                C
    000006I      10    FORMAT(5I5,1P4E15.6)
    00001AI      12    FORMAT(5X,'ENTER DELT FOR CASE',I5,', FORMAT F5.3')
    000044I      13    FORMAT(F5.3)
    00004AI      15    FORMAT(I5)
    00004EI      18    FORMAT(5X,'ENTER NUMBER OF CASES TO BE PLOTTED, FORMAT I5')
    000082I      20    FORMAT(1P3E15.6)
    00008CI      30    FORMAT(4I5,1P4E15.6)
    00009AI      40    FORMAT(1P5E16.6)
    0000A4I      50    FORMAT(10X,'NUMBER OF PRESSURE POINTS READ =',I5,/,
                      &  10X,'NUMBER EXPECTED ='I5)
    0000E4I      60    FORMAT(10X,'NUMBER OF XPSI POINTS READ =',I5,/,
                      &  10X,'NUMBER EXPECTED =',I5)
    000120I      70    FORMAT(I10)
                C
                C      READ NUMBER OF CASES TO BE PROCESSED
                C
    000124I            WRITE(9,18)
    00251CI            READ(5,15) NGEOMS
    00253CI            NGEOM=0
                C
    002544I     100    CONTINUE
    002544I            NGEOM= NGEOM + 1
                C
                C      READ HEADER INFORMATION FOR PRESSURE DATA
                C
    002552I            READ(8,10) NYS,NXSLOT,NSLOTS,NMIN,NMAX,XSDMIN,XSDMAX,XSD,YSD
    002590I            WRITE(6,10) NYS,NXSLOT,NSLOTS,NMIN,NMAX,XSDMIN,XSDMAX,XSD,YSD
                C
                C      ENTER DELT
                C
    0025D0I            WRITE(9,12) NGEOM
    0025F0I            READ(5,13) DELT
                C
                C      READ PRESSURE DATA
```

```
                C
002610I                NYSP1=NYS+1
00261EI                NYSP2=NYS+2
00262CI                DO 200 I=1,NYSP2
002640I                N=I
00264CI                READ(8,20,ERR=300) Y(I),P1(I),P2(I)
00260CI          200   CONTINUE
0026F4I          300   CONTINUE
0026F4I                WRITE(6,50) N,NYSP2
                C
                C      READ HEADER INFORMATION FOR STREAMLINE DATA
                C
002718I                READ(7,30) NXSLOT,NSLOTS,NMIN,NMAX,XSMIN,XSMAX,XSINK,YSINK
002754I                WRITE(6,30) NXSLOT,NSLOTS,NMIN,NMAX,XSMIN,XSMAX,XSINK,YSINK
                C
                C      READ STREAMLINE DATA
                C
002790I                NX1=NXSLOT+1
00279EI                M=0
0027A6I          400   M=M+1
0027B4I                READ(7,70) IMAX(M)
0027E8I                IMIN=1
0027F0I                IMX=5
0027F8I          500   DO 600 J=1,NX1
00280CI                READ(7,40) (ZPSI(I,J,M),I=IMIN,IMX)
0028ACI          600   CONTINUE
0028C4I                IF(IMX.GE.NX1) GO TO 700
0028DCI                IMIN=IMIN+5
0028EAI                IMX=IMX+5
0028F8I                IF(IMX.GT.NX1) IMX=NX1
002916I                GO TO 500
00291AI          700   CONTINUE
                C
00291AI                DO 800  J=1,NX1
00292EI                N=J
00293AI                READ(7,40,ERR=900) XPSI(J,M)
00297CI          800   CONTINUE
002994I          900   CONTINUE
002994I                WRITE(6,60) N,NX1
0029B8I                IF(M.EQ.1) GO TO 400
                C
                C      PREPARE PRESSURE PLOTS
                C
0029CCI                CALL PLOTP(NYS,Y,P1,P2,NMIN,NMAX,XSD,YSD,DELT)
                C
                C      PREPARE STREAMLINE PLOTS
                C
002AC4I                CALL PLOTST(NXSLOT,NSLOTS,NMIN,NMAX,XSMIN,XSMAX,XSINK,YSINK,
                     &  ZPSI,XPSI,IMAX,DELT)
                C
                C      LOOP BACK TO LINE 100 FOR NEXT CASE AS NEEDED
```

```
               C
     002A48I         IF(NGEOMS.GT.NGEOM) GO TO 100
               C
     002A5EI         CALL DRAW(0,0,0,9999)
               C
     002AA4I         END

NO  ERRORS:F7D  R04-00      MAINPROG    .MAIN     06/24/81  08:40:23  TABLE SPACE:   4 KB
STATEMENT BUFFER:   20 LINES/1321 BYTES    STACK SPACE: 133 WORDS
```

```
000000I          SUBROUTINE PLOTP(NYS,Y,P1,P2,NMIN,NMAX,XSD,YSD,DELT)
            C
            C    TO PLOT SLOT END PRESSURES, P1(Y), SLOT CLOSEST TO THE SUCTION
            C      AND P2(Y), SLOT FURTHEST FROM THE SUCTION.
            C
000004I          DIMENSION Y(103),P1(103),P2(103)
            C
000004I          NYSP2=NYS+2
000026I          SAME = 9999.
000032I          CALL SCAN(P1,Y,-NYSP2,440)
000090I          CALL DRAW(P1,Y,NYSP2,441)
0000E0I          CALL DRAW(P2,Y,NYSP2,6443)
000130I          CALL AXES(26.2,'P (DIMENSIONLESS PRESSURE)',24.1,
                &  'Y (DIMENSIONLESS HEIGHT)')
0001CCI          CALL MODE(5,SAME,SAME,SAME)
0001F8I          CALL NOTE(2.0,7.7,'DELT =',6)
00026CI          CALL NOTE(2.7,7.7,DELT,1002)
0002B0I          CALL NOTE(2.0,7.4,'XSD =',5)
000324I          CALL NOTE(2.6,7.4,XSD,1003)
000368I          CALL NOTE(3.1,7.4,', YSD =',7)
0003DCI          CALL NOTE(3.9,7.4,YSD,1003)
000420I          CALL NOTE(2.0,7.0,'LINE = SLOT',11)
000494I          CALL NOTE(3.3,7.0,NMIN,0)
0004D8I          CALL NOTE(2.0,6.8,'DOTS = SLOT',11)
00054CI          CALL NOTE(3.3,6.8,NMAX,0)
000590I          CALL DRAW(0.,0.,1,9000)
0005DCI          RETURN
0005E2I          END
```

NO ERRORS:F7D R04-00 SUBROUTINE PLOTP 06/24/81 08:40:35 TABLE SPACE: 3 KB
STATEMENT BUFFER: 20 LINES/1321 BYTES STACK SPACE: 59 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION

```
0000001          SUBROUTINE PLOTST(NXSLOT,NSLOTS,NMIN,NMAX,XSMIN,XSMAX,XSINK,YSINK,
               &  ZPSI,XPSI,IMAX,DELT)
            C
            C    TO PLOT STREAMLINES FOR THE SLOT BOTTOM FOR SLOTS
            C      NMIN = SLOT CLOSEST TO THE SUCTION
            C      NMAX = SLOT FRUTHEST FROM THE SUCTION
            C
000004I          DIMENSION ZPSI(31,31,2),XPSI(31,2),X(31),Z(31),IMAX(2),NM(2)
            C
            C    WE WILL FORM A PAIR OF VECTORS, X(I) AND Z(I) TO BE PLOTTED.
            C    THE PSI = 0. STREAMLINES SETS THE SCALE FOR THE PLOT, DO
            C      IT FIRST.
            C
000004I          NM(1)=NMIN
000122I          NM(2)=NMAX
00012CI          SAME = 9999.
000138I          NX1=NXSLOT+1
000146I          DX = 1./FLOAT(NXSLOT)
00016AI          M=0
000172I   50     M=M+1
000180I          LIM=IMAX(M)+1
            C
            C    LOAD DATA FOR STAGNATION STREAMLINE.  THIS WILL SET THE
            C      SIZE OF THE PLOT WHEN CALL SCAN IS USED BELOW.
            C
00019CI          X(1) = 0.5
0001A6I          Z(1) = 1.
            C
0001B0I          DO 100 I=2,NX1
0001C4I          X(I) = 0.5 - DX*FLOAT(I-1)
000202I          Z(I) = 0.0
000214I   100    CONTINUE
            C
00022CI          CALL SCAN(Z,X,-NX1,440)
000263I          CALL MODE(2, 7.0,SAME, SAME)
0002A0I          CALL MODE(3, 9.0,SAME, SAME)
000208I          CALL MODE(8,-1.75, 0.5, 0.0)
000328I          CALL MODE(9,-0.8,0.20, 0.0)
000378I          CALL DRAW(Z,X,NX1,441)
0003A4I          DO 120 I=1,NX1
0003B8I          Z(I)=-Z(I)
000306I   120    CONTINUE
0003EEI          CALL DRAW(Z,X,NX1,441)
            C
            C    NOW PROCEED TO THE OTHER STREAMLINES
            C    CODING FOLLOWS CLOSELY THAT OF PICUP1.FTN
            C
            C          INDEX J (BELOW) REFERS TO THE STREAMLINE
            C          INDEX I REFERS TO THE X LOCATION OF THE INTEGRAND TERM
            C            BEING FORMED.
            C
```

```
00041CI         DO 300 J=LIM,NXSLOT
000434I         JM1=J-1
000442I         X(1)=DX*FLOAT(JM1)-0.5
000468I         Z(1)=1.0
          C
000472I         DO 200 I=1,JM1
000486I         II=J-I
000498I         IIM1=II-1
0004A6I         IP1=I+1
0004B4I         X(IP1)=DX*FLOAT(IIM1)-0.5
          C     TEST=X(IP1)+0.001
0004E4I         IF(X(IP1).GE.XPSI(J,M)) GO TO 180
00051CI         X(IP1)=XPSI(J,M)
000548I         Z(IP1)=1.0
00055AI         IPTS=IP1
000566I         GO TO 201
          C
00056CI     180 CONTINUE
00056CI         Z(IP1)=ZPSI(II,J,M)
0005A4I         IPTS=IP1
0005B0I     200 CONTINUE
0005C8I     201 CONTINUE
          C
0005C8I         CALL DRAW(Z,X,IPTS,441)
0005F4I         DO 250 I=1,NX1
000608I         Z(I)=-Z(I)
000626I     250 CONTINUE
00063EI         CALL DRAW(Z,X,IPTS,441)
          C
00066CI     300 CONTINUE
          C
000684I         CALL AXES(23.2,'Z (DIMENSIONLESS WIDTH)',24.1,
               &  'X (DIMENSIONLESS LENGTH)')
000720I         NN=NM(M)
000732I         CALL MODE(5,SAME,SAME,SAME)
00075CI         CALL NOTE(2.8,8.2,'DELT =',6)
0007D0I         CALL NOTE(3.5,8.2,DELT,1002)
000814I         CALL NOTE(2.2,7.9,'XSINK =',5)
000888I         CALL NOTE(2.8,7.9,XSINK,1003)
0008CCI         CALL NOTE(3.4,7.9,', YSINK =',7)
000940I         CALL NOTE(4.2,7.9,YSINK,1003)
000984I         CALL NOTE(3.0,7.5,'SLOT',4)
0009F8I         CALL NOTE(3.5,7.5,NN,0)
          C
          C     INDICATE THE SOLID BOUNDARIES WHICH DELIMIT THE SLOT
          C       AND VOID NEAR THE MOUTH OF THE SLOT.
          C
000A3CI         Z(1)=-1.5
000A46I         X(1)=-0.5
000A50I         Z(2)=-1.0
000A5AI         X(2)=-0.5
```

```
000A64I          Z(3)=-1.0
000A6EI          X(3)= 0.5
000A78I          Z(4)= 1.0
000A82I          X(4)= 0.5
000A8CI          Z(5)= 1.0
000A96I          X(5)=-0.5
000AA0I          Z(6)= 1.5
000AAAI          X(6)=-0.5
000AB4I          CALL DRAW(Z,X,6,441)
            C
000AE8I          CALL DRAW(0.,0.,1,9000)
            C
000B34I          IF(M.EQ.1) GO TO 50
            C
000B48I          RETURN
000B4EI          END

NO  ERRORS:F7D  R04-00     SUBROUTINE  PLOTST    06/24/81  08:41:03  TABLE SPACE:   4 KB
STATEMENT BUFFER:   20 LINES/1321 BYTES    STACK SPACE: 154 WORDS
SINGLE PRECISION FLOATING PT SUPPORT REQUIRED FOR EXECUTION
```

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5. AUTHOR(S)

Howard R. Baum and John A. Rockett

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

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10. SUPPLEMENTARY NOTES

[ ] Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

An analysis of the fluid flow and mass transfer induced by ventilation systems in containership holds was carried out. The work was performed in support of the U.S. position before a committee of the International Convention on Safety to Life at Sea. The analysis consists of a detailed calculation of the forced motion through an interconnected set of narrow, stably stratified vertical air passages which represent an idealized containership holds the results of this calculation are then used in a study of the concentration boundary layers formed by the pickup of spill material assumed to lie at the bottoms of the air passages. The result is a set of formulae which determine the rate of extraction of spill material as a function of hold geometry, ventilation parameters, and ambient stratification. The results are incorporated in a computer program which is described in detail. A variety of computed results are presented, together with a listing of the program. The results indicate the crucial importance of locating the extractor as close to the hold bottom as technically possible.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Cargo ships; fires hazardous materials; modeling; stratified flow; ventilation

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