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BEHAVIOR OF DROPLETS EVAPORATING IN HIGH-TEMPERATURE CONVECTIVE ENVIRONMENTS

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BEHAVIOR OF DROPLETS EVAPORATING IN HIGH TEMPERATURE CONVECTIVE ENVIRONMENTS

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This study is concerned with the behavior of small droplets in a high temperature convective environment of their own vapor at low Reynolds numbers. The behavior of large droplets evaporating in a stagnant environment at quasi steady state is well known. This solution is used as a basis, to which corrections are applied, for the evaporation of very small droplets and for the evaporation in convective flow.

Investigation of the rapid evaporation of a small droplet reveals that the evaporation rate law changes when the droplet diminishes in size to the order of the mean free path of the vapor molecules. Generally the evaporation rate will be lowered. However, for small droplets which are near their critical temperature, the reverse behavior is expected. Furthermore, the correction for the small droplet is shown to be independent of the forced convective conditions. The specific purpose of this study is to obtain an expression for the drag exerted on the droplet by the convective environment. Approximate analytic and numerical solution were obtained for the problem although the presence of the convective flow field does not alter the total evaporation rate, the drag exerted and rapidly evaporating drop is lowered appreciably, compared to the case of Stokes flow.

s - 1/N

T - temperature

T_b^* - boiling point temperature

u - radial velocity component

U - energy

v - tangentiel velocity component

v_s - acoustic velocity

γ - $|v^*(\infty)| / \overline{u^*(R)}$

Δ - $\Delta \hat{H}^* / \hat{c}_p^* T_R^*$

ΔH - latent heat of vaporization

θ - angle

θ^b - $T^*(\infty) / T_b^*$

κ - evaporation constant

ρ - density

ρ^L - liquid density

τ - stress tensor

τ - $T_b^*/T^*(R)$

$*$ - dimensional quantity

1. INTRODUCTION

1.1. General description of the problem.

This study is concerned with the behavior of droplets evaporating in high temperature convective environments. The general behavior of a droplet in such a state is obviously subject to a large number of different effects. However, only those few having a principle influence on its typical behavior will be taken into account in this analysis.

The description of the evaporation of a single droplet may seem to be of academic interest only. However, the behavior of sprays of droplets cannot be fully understood without some knowledge about the characteristic behavior of a single droplet, its evaporation rate and its ballistic behavior.

The behavior of a droplet is distinctly different from that of an inert particle. The evaporating droplet constitutes essentially a mass source and a heat sink and maintains in its neighbourhood a region of high gradients of fluid properties and an appreciable mass flux. When the droplet vaporizes in convective surroundings, it generates a macroscopically directed impulse flux, and, consequently, its drag is of a distinctly different nature than that for an inert particle.

The specific purpose of this study is not only to provide a description of the behavior of very small droplets which evaporate rapidly, but also to obtain an expression for the drag

exerted by the convective environment on the droplet at low Reynolds numbers.

The evaporation of a drop, which is exposed to very hot surroundings is completely heat transfer controlled. Mass transfer effects are therefore disregarded in this study and the droplet is thought to be evaporating in an atmosphere which consists of its own vapor. Furthermore the droplet is considered to be evaporating at quasi steady state.

The initial transient effects, which are important when the drop is injected into the vapor, are neglected. It is assumed that the gradients are already developped and that the droplet has reached its thermodynamic equilibrium temperature. In addition radiation and gravity effects are neglected.

In the description of the proces the vapor is assumed to obey the ideal gas law and to have constant heat capacity and constant viscosity and thermal conductivity. These properties are actually functions of temperature and, less significantly, of pressure. However, their variation is obviously of lesser importance than the variation of temperature and pressure. The heat transfer is directly dependent on the gradient of the temperature near the droplet surface, and, although the pressure hardly varies at all as will be seen, its influence on the drag force exerted on the drop is quite decisive.

After the problem has been simplified to this extent, the evaporation of a large droplet in a stagnant atmosphere can

be described, resulting in the familiar law which states that the total rate of change of the mass of the droplet is directly proportional to the size of its radius[1]. This solution for a large droplet evaporating steadily in a stagnant atmosphere, provides the basis of the study. The analysis extends this solution to the case of a small droplet evaporating in a convective environment.

The study actually deals with two effects, the corrections of the solution for the evaporation of small droplets and the corrections for the evaporation in a convective environment. The two effects can be treated independently and the corrections prove to be subject to superposition.

The solution for the small droplet is outlined first. When the droplet becomes small, the radial vapor velocity at the surface becomes appreciable. The correction is obtained by taking into account the kinetic energetic effects as well as the viscous dissipation. These effects alter the pressure at the surface of the drop and hence the temperature. Therefore the driving force for heat transfer is influenced and the rate of evaporation is changed.

For the case of a droplet evaporating in a convective environment a numerical solution as well as an approximate analytic solution are obtained for small Reynolds numbers. The general problem is first simplified analytically by assuming to be of a form describing the dependence on the angle which

satisfies the equations and the boundary conditions. Due to the axial symmetry of the problem, the variables depend only on the distance from the drop and the angle with the direction of the forced convective flow. The dependence on angle can be eliminated by assuming a suitable form of the solution which satisfies the applicable equations and boundary conditions. The resulting set of ordinary linear differential equations is then solved by polynomial approximation and numerical methods. The pressence of the convective flow field proves to have no influence on the evaporation rate. However the drag exerted on the rapidly evaporating drop can be shown to be distinctly different from the drag on an inert particle in similar conditions.

1.2 Background of the Study.

Since the understanding of the characteristic behavior of droplets is of major importance for the analysis of various spray systems, such as combustion in liquid fueled rocket engines, the evaporation rate and the closely related combustion rate of a single droplet has been subject to numerous investigations.

The first description of the evaporation of a droplet was given by Froessling[1] for a diffusion controlled process at relatively low evaporation rates. It was shown that the total rate of evaporation is directly proportional to the size of the radius of the droplet, or $\dot{M}^* = \kappa^* R^*$, where $\dot{M}^*$ is the total rate

of change of mass of the drop, R* is the radius and κ^* is the evaporation constant.

Ranz and Marshall[2] extended the treatment for a heat transfer controlled process at relatively low evaporation rates. Godsave[3] and later Goldsmith and Penner[4], who were able to predict the evaporation constant very closely, treated the case of high mass flux rate in connection with combustion. Most of the experimental work, however, was done suspending the droplets with the use of a filament.

Of the investigations pertaining directly to scope of this study only a few are of interest. The transient behavior of the droplet after injection in the system was described by Williams[5] and his theoretical results agree very well with his experiments, which show that only a very short time is required for the development of the quasi steady state.

The evaporation rate of very small droplets was described by Monchick and Reisse[6]. They showed on the basis of molecular kinetic arguments, that the total rate of change of the mass of a droplet of the size of the mean free path of the vapor molecules must be lower than is expected from the law governing the evaporation of a large drop. It is interesting to note, that this result is derived in this study in a straightforward manner, using the macroscopic equations applicable for the system.

Very little work has been reported on the vaporization

under conditions of turbulent gas flow. Most of this work is experimental, having only a very limited range of applicability. Maisel and Sherwood[7] suspending model droplets at fixed positions did not find any appreciable influence of the convective flow on the evaporation rate.

The work of Ingebo[8] should be mentioned. He actually calculated drag coefficients of droplets in sprays at high evaporation rates on the basis of his observations and found these of the same order as those for solid spheres. His results however can be questioned, since no direct measurement was made.

Reference should be made to the investigation of Ranz and Dickson[9], which deals with mass and heat transfer rates for large gradients of concentration and temperature. Their extensive work, however, is concerned with plane interfaces, and is not directly applicable to problems involving curved surfaces.

As far as the evaporation in a convective environment is concerned it can be stated that the analysis presented in this study is opposed to the classical treatment of spheres in convective flow of low Reynolds numbers, such as given by Acrivos and Taylor[10]. Instead of using the Stokes flow pattern, the solution for the evaporation of the drop is used as a basis for the analysis.

2. MATHEMATICAL DEVELOPMENT OF THE PROBLEM

2-1. General Consideration.

The study is limited to the description of the behavior of a droplet, which evaporates into its own vapor at quasi steady state. The droplet is thought to be in high temperature environments and therefore to evaporate rapidly; the initial transient effects, however, are disregarded. Furthermore the droplet is thought to be small, such that the convective effects do not alter its spherical form. The vapor is assumed to have constant heat capacity and constant transfer properties -viscosity and thermal conductivity- and is supposed to obey the ideal gas law.

The general equations applicable to the system are discussed first. The solution for a large drop evaporating in a stagnant atmosphere will be outlined next and finally this solution will be used to compute corrections for a small droplet evaporating in stagnant atmosphere and for the evaporation of a droplet in convective environment. These corrections will prove to be independent and superimposible.

The behavior of the steadily evaporating droplet is completely dependent on the state of the surrounding fluid. Since the transient effects are negligible, the pressure and temperature may be considered uniform within the drop and over

the droplet surface as will be seen later. Heat is transferred through the fluid towards the droplet surface and the resulting mass flux is carried outward by the fluid.

In describing this process, the conservation equations of mass, momentum and energy in their nondimensional form are used. Gravity effects and radiation are neglected. In order to determine the relative significance of the different terms in the equations it is convenient, that the variables be of the same order of magnitude in the neighbourhood of the drop. Therefore, all variables are made nondimensional by dividing by their corresponding averaged value at the droplet surface, such that:

radial distance: $r=r^*/R^*$, density : $\varrho=\varrho^*/\varrho^*(R)$

temperature : $T=T^*/T^*(R)$, pressure : $p=p^*/p^*(R)$

radial velocity: $u=u^*/\overline{u^*(R)}$, tang.vel.: $v=v^*/\overline{u^*(R)}$

where dimensional variables are marked with an asterisk and R^* represents the radius of the spherical drop. The radial component of the velocity vector $\underline{v}$ is represented by u and the tangential component by v; v^* is made nondimensional by dividing by $\overline{u^*(R)}$. Note that the bar is omitted from $p^*(R)$, $T^*(R)$ and $\varrho^*(R)$, because cases where this value is not uniform over the droplet surface will not be encountered in this study.

The general equations may now be written assuming the heat capacity per unit mass $\hat{c}_p^*$, conductivity k^* and viscosity μ^* are constants.

The continuity equation is:

$$\nabla \cdot \rho^* \underline{v}^* = 0$$

or

$$\nabla \cdot \rho \, \underline{v} = 0 \qquad (2.1\text{-}1)$$

The momentum equation is:

$$\rho^* \underline{v}^* \cdot \nabla \underline{v}^* = -\nabla p^* - [\nabla \cdot \underline{\underline{\tau}}^*]$$

or

$$Re_v \, \rho \, \underline{v} \cdot \nabla \underline{v} = -\frac{Re_v}{K Ma^2} \nabla p - [\nabla \cdot \underline{\underline{\tau}}] \qquad (2.1\text{-}2)$$

where $\underline{\underline{\tau}}$ is the stress tensor defined by

$$\underline{\underline{\tau}}^* = -\mu^* [\nabla \underline{v} + (\nabla \underline{v})^T] + \frac{2}{3} \mu^* \underline{\underline{I}} \, \nabla \cdot \underline{v} \qquad (2.1\text{-}3)$$

and

$$\underline{\underline{\tau}} = \underline{\underline{\tau}}^* R^* / \mu^* u^*(R)$$

The thermal energy equation is:

$$\rho^* \underline{v}^* \hat{c}_p^* \cdot \nabla T^* = \nabla \cdot (k^* \nabla T^*) + \underline{v}^* \cdot \nabla p^* - (\underline{\underline{\tau}}^* : \nabla \underline{v}^*)$$

or

$$Re_v \, Pr \, \rho \, \underline{v} \cdot \nabla T = \nabla \cdot \nabla T + \frac{K-1}{K} Re_v \, Pr \, \underline{v} \cdot \nabla p - (K-1) Ma^2 Pr (\underline{\underline{\tau}} : \nabla \underline{v}) \qquad (2.1\text{-}4)$$

where the terms reading from the left stand for: convection

conduction, reversible work and dissipation. The equation of state is:

$$p^* = \rho^* \hat{R}^* T^* \qquad \text{or} \qquad p = \rho T \qquad (2.1\text{-}5)$$

where $\hat{R}^*$ = gas constant per unit mass.

The newly arisen characteristic numbers are:

$$Re_v = \frac{\rho^*(R)\,\overline{u^*(R)}\,R^*}{\mu^*} \quad , \qquad Pr = \frac{\mu^*\,\hat{c}_p^*}{k^*}$$

$$Ma = \overline{u^*(R)} \,/\, v_s^*(R) \quad , \qquad K = \frac{\hat{c}_p^*}{\hat{c}_p^* - \hat{R}^*} = \hat{c}_p^* \,/\, \hat{c}_v^*$$

and $v_s^*(R)$ = acoustic velocity in the vapor at the droplet surface = $\sqrt{K\,\hat{R}^*\,T^*(R)}$. Re_v is not an ordinary Reynolds number as it involves the radial velocity due to evaporation as does the Mach number, Ma. The appearance of the Mach number indicates that the radial vapor flux has to stay within sensible limits. As will be seen Re_v is of order unity for a rapidly evaporating droplet and Ma equals zero for a large droplet.

2-2. Large Droplet in Stagnant Environment

2-2.1 Analysis.

The set of equations can be easily solved for a large drop evaporating in the stagnant atmosphere of its own vapor, the system being characterized by spherical symmetry. The Mach number approaches zero for this case, because the radial velocity at the surface is very small for a large drop as will be explained later. The continuity equation can be written as

$$\frac{1}{r^2}\frac{d}{dr}(r^2 \rho u) = 0 \qquad \text{B.C. at } r = 1\text{: } r^2 \rho u = 1$$

Therefore

$$r^2 \rho u = 1 \tag{2.2-1}$$

Assuming Ma $\doteq$ 0 the equation of motion reduces to

$$\frac{dp}{dr} = 0 \qquad \text{B.C. at } r = 1\text{: } \quad p = 1$$

Therefore p = 1 and the pressure is uniform throughout the domain. Moreover, since always $p = \rho T$ it follows

$$\rho = \frac{1}{T} \quad , \quad u = \frac{T}{r^2} \tag{2.2-2}$$

The equation of thermal energy can be written. The boundary condition is obtained by making an energy balance on the liquid-gas interface.

$$\dot{M}^* \hat{\mathcal{H}}^*_{(\text{Liquid})} = -4\pi R^{*2} \rho^*(R)\, u^*(R) \left\{ \hat{\mathcal{H}}^*(R) + \tfrac{1}{2} u^{*2}(R) \right\} + 4\pi R^{*2} k^* \left(\frac{dT^*}{dr^*}\right)_{r^*=R^*} - 4\pi R^{*2} \tau^*_{rr}(R)\, u^*(R) \tag{2.2-3}$$

where $\dot{M}^*$ is the total rate of change of mass of the drop, and

$\hat{H}^*$ is the enthalpy per unit mass. The terms denote reading from the left: the total gain of enthalpy of the droplet, the transport of enthalpy and kinetic energy by the vapor, the heat conduction and the work done by the vapor against the viscous forces. Note that $\dot{M}^* = -4\pi R^{*2}\rho^* u^*(R)$ and $\hat{H}^* = \hat{H}^*(R) + c_p^*(T^*-T^*(R))$. Actually the expression describing $\dot{M}^*$ is not exact, because it involves $u^*(R)$, which is the vapor velocity at the droplet surface. However, it should involve the vapor velocity relative to the moving surface instead. As will be seen later this correction is small and may be omitted.

Since Ma is assumed to be zero, kinetic energetic effects are negligible, no work is done by the vapor and all the heat conducted towards the droplet surface is used to provide the latent heat of vaporization ($\Delta \hat{H}^*$):

$$\rho^*(R)\, u^*(R)\, \Delta \hat{H}^* = k^* \left(\frac{dT^*}{dr^*}\right)_{r^*=R^*}$$

or

$$Re_v^b \cdot Pr \;\; \Delta^b = \left(\frac{dT}{dr}\right)_{r=1}$$

The parameter stands for $\Delta^b = \Delta\hat{H}^*/\hat{c}_p^*\, T^*(R)$. Superscript "b" is added to denote that $T^*(R)$ actually equals the boiling temperature of the liquid at the applied pressure $p^*(\infty)$. The equation reduces to

$$Re_v^b \cdot Pr \; \frac{1}{r^2}\frac{dT}{dr} = \frac{1}{r^2}\left\{\frac{d}{dr}\left(r^2\frac{dT}{dr}\right)\right\} \qquad \text{B.C. at } r=1,\; T=1, \frac{dT}{dr} = Re_v^{\,b}\, Pr^b$$

Therefore:

$$Re_v^b \, P_r \left(T - 1 + \Delta^b\right) = r^2 \frac{dT}{dr}$$

and:

$$Re_v^b \, P_r \left(1 - \frac{1}{r}\right) = \log\left[\frac{T - 1 + \Delta^b}{\Delta^b}\right]$$

or:

$$T = 1 - \Delta^b \left[1 - e^{Re_v^b P_r (1 - \frac{1}{r})}\right] \qquad (2.2\text{-}3)$$

Since P_r is a constant for most gases ($\sim 3/4$), Re_v^b is now completely defined by applying the boundary condition at infinity:

$$Re_v^b \, P_r = \log\left\{\frac{\theta^b - 1 + \Delta^b}{\Delta^b}\right\} \qquad (2.2\text{-}4)$$

where $\theta^b = T^*(\infty) / T^*(R)$. Clearly Re_v^b is a constant for given $\Delta^b(p^*(\infty) \rightarrow T^*(R))$ and $\theta^b(T^*(\infty))$.

Since Re_v^b is a constant, the radial velocity at the drop surface approaches zero when the radius of the drop is very large and, indeed, Ma = 0. Furthermore, the total rate of change of the mass of the drop is:

$$\dot{M}^* = \rho^{L*} \, 4\pi R^{*2} \frac{dR^*}{dt} = -4\pi R^{*2} \rho^*(R) u^*(R) = -4\pi \mu^* Re_v^b R^* = -\kappa^* R^*$$

where ρ^{L*} is the density of the liquid. This is the familiar linear law with the evaporation constant κ^*. In integrated form

$$R^{*2} - R_0^{*2} = -\kappa^{*\prime} t^* \qquad (2.2\text{-}5)$$

where $\kappa^{*\prime} = \kappa^*/2\pi\rho^{L*}$, t^* = time and R_0^* is the radius of the

drop at $t^* = 0$.

2-2.2 Transient Terms.

The problem of the evaporation of small droplets can also be derived when the transient effects are taken into account. It is reported[5] that the transient effects influence the evaporation constant and that this influence is bigger than one percent for about one tenth of the lifetime. For small droplets the time constant for reaching the steady state of evaporation becomes lower.

The error arising from the assumption that transient terms are negligible in the above derivation may simply be estimated by comparing the time derivative of a quantity and the convective terms of this quantity at the same point. This is now illustrated for the density:

$$\frac{\partial \rho^*}{\partial t^*} = \frac{d\rho^*}{d\frac{r^*}{R^*}} \cdot \frac{\partial r^*/R^*}{\partial t^*} = -\frac{r^*}{R^{*2}}\frac{dR^*}{dt}\rho^{*\prime} = \left(\frac{\rho^*(R)}{\rho^{\infty *}}\right)\frac{r^* u^*}{R^{*2}}\cdot\rho^{*\prime}$$

and

$$u^*\frac{\partial \rho^*}{\partial r^*} = \rho^{*\prime}\cdot u^*\frac{\partial r^*/R^*}{\partial r^*} = \frac{v_r^*}{R^*}\cdot\rho^{*\prime}$$

thus: $$\frac{\partial \rho^*}{\partial t^*} \Big/ u^*\frac{\partial \rho^*}{\partial r^*} = \left(\frac{\rho^*(R)}{\rho^{\infty *}}\right)\cdot\frac{r}{u} = \left(\frac{\rho^*(R)}{\rho^{\infty *}}\right)\cdot\frac{r^s}{T}$$

Since $\rho^*(\text{liq})/\rho^*(R) \sim 10^3$ the transient terms become important only if $r > 10$, but the radial velocity is at that point already down to a few percent for moderate values of $\theta^b(T^*(\infty)/T^*(R))$. It is seen that "infinity" is really close by; the error, however introduced by omission of transient terms is negligible.

2-3. Corrections for Evaporation of Small Droplets in stagnant environments

2-3.1. Analysis.

According to the linear evaporation law derived for large droplets, the Reynolds number describing the evaporation is a constant independent of the size of the droplet, thus $Re_v^b = \frac{\rho^*(R)u^*(R)R^*}{\mu^*}$ = constant. However, when the droplet radius R* becomes small, the radial mass flux at the droplet surface, $\rho^*(R)u^*(R)$, would then accordingly approach infinity. This, of course, cannot be true. When the radial velocity at the surface increases, the Mach number is no longer zero, and the kinetic energetic effects, which have been neglected in the derivation of the linear law become important.

A first approximation of the behavior of a small droplet evaporating in a stagnant atmosphere can be obtained by a perturbation of the solution for a large droplet. The perturbation analysis is used here to linearize the equations of motion and thermal energy. This is accomplished by assuming the temperature and the pressure to be of the form: $T=T_0+(K-1)Ma^2T_1+$ $+(K-1)Ma^4T_2+\ldots$ and $p=p_0+KMa^2p_2+\ldots$ and neglecting the terms of order (Ma^4) and higher.

The equation of energy can be written:

$$-\nabla\cdot\left[\rho^*\,\underline{v}^*\left\{U^*+\frac{p^*}{\rho^*}+\frac{1}{2}u^{*2}\right\}\right]+\nabla\cdot(k^*\nabla T^*)-\nabla\cdot[\underline{\underline{\tau}}^*\cdot\underline{v}^*]=0$$

where $\hat{U}^*$ is the energy per unit mass. The equation of total energy is chosen here, because it is readily integrated due to the spherical symmetry of the stagnant atmosphere in which the droplet is evaporating. Integrating once from the surface of the droplet outward, results in:

$$\dot{M}^* \hat{\mathcal{H}}^*(\text{Liquid}) = -4\pi r^{*2} \rho^* u^* \left\{ \hat{\mathcal{H}}^* + \tfrac{1}{2} u^{*2} \right\} + 4\pi r^{*2} k^* \frac{dT^*}{dr^*} - 4\pi r^{*2} \tau_{rr}^* u^*$$

where $\hat{H}^*$ is the enthalpy per unit mass. Noting that $\dot{M}^* = -4\pi R^{*2} \rho^*(R) u^*(R)$ and $\hat{H}^* = \hat{H}^*(R) + c_p^*(T^* - T^*(R))$ and $\tau_{rr}^* = -\frac{4}{3}\mu^* \left\{ \frac{du^*}{dr^*} - \frac{u^*}{r^*} \right\}$, the equation can be written in its nondimensional form with the use of the continuity equation, $r^2 \rho u = 1$,

$$Re_v \, Pr (T - 1 + \Delta) = r^2 \frac{dT}{dr} - (K-1) Ma^2 \left[Re_v Pr \tfrac{1}{2} u^2 + \tfrac{4}{3} Pr \left(\frac{du}{dr} - \frac{u}{r} \right) u r^2 \right] \quad (2.3\text{-}1)$$

Actually, $\dot{M}^* \hat{H}^*(\text{liquid})$ is not the exact energy lost by the droplet, because energy is released by the change of surface area by the amount of $-\sigma^* \frac{d 4\pi R^{*2}}{dt}$, where σ^* is the surface tension. If this effect cannot be disregarded, Δ should be replaced by $\Delta' = \left(\Delta \hat{H}^* - \frac{2\sigma^*}{R^* \rho^{L*}} \right) / \hat{c}_p^* T^*(R)$ Although it is not a limitation for the development, the Prandtl number is taken, for convenience, to be $\frac{3}{4}$ as it is for most gases.

The temperature is now assumed to be of the form: $T = T_0 + (K-1) Ma^2 T_1$, and has B.C. at $r = 1$: $T_0 = 1$, $T_1 = 0$: it follows:

$$T_0 = 1 - \Delta \left(1 - e^{Re_v Pr (1 - \frac{1}{r})} \right) \quad (2.3\text{-}2)$$

and

$$r^2 \frac{d}{dr}\left\{T_1 + \tfrac{1}{2}u^2\right\} - Re_v Pr\left\{T_1 + \tfrac{1}{2}u^2\right\} = r\,u^2 \qquad (2.3\text{-}3)$$

Note that this result is not trivial, because it involves Re_v instead of $Re_v{}^b$.

Equation of motion can be written as

$$Re_v\, \rho\, u \frac{du}{dr} = -\frac{Re_v}{K Ma^2}\frac{dp}{dr} + \frac{4}{3}\frac{1}{r^3}\frac{d}{dr}\left\{r^3\left(\frac{du}{dr} - \frac{u}{r}\right)\right\} \qquad (2.3\text{-}3a)$$

assuming the pressure to be of the form: $p = 1 + KMa^2 p_1$, the equation reduces to:

$$Re_v \frac{dp_1}{dr} = -\frac{Re_v}{r^2}\frac{du}{dr} + \frac{4}{3}\frac{1}{r^3}\frac{d}{dr}\left\{r^3\left(\frac{du}{dr} - \frac{u}{r}\right)\right\}$$

with B.C. at $r = 1$ $p_1 = 0$

Assuming $Re_v = Re_v{}^b + \mathcal{O}(Ma^2)$ and noting that:

$$u = \frac{1 - \Delta^b\left[1 - e^{Re_v^b Pr(1-\frac{1}{r})}\right]}{r^2} + \mathcal{O}(Ma^2),$$

the equations for T_1 and p_1 may be rewritten using a change of variable, $x = 1 - 1/r$, and denoting $a = Re_v{}^b Pr$:

$$\frac{d}{dx}\left\{T_1 + \tfrac{1}{2}u^2\right\} - a\left\{T_1 + \tfrac{1}{2}u^2\right\} = (1-x)^3\left[1 - \Delta^b(1 - e^{ax})\right]$$

$$\frac{dp_1}{dx} = 2(1-x)^3\left[1 - \Delta^b(1 + e^{ax})\right]$$

with B.C.: $r = 1$, $p_1 = 0$, $T_1 = 0$. These equations can be integrated directly to give:

$$p_1 = -\tfrac{1}{2}(1-\Delta^b)(1-x)^4 - \frac{2\Delta^b}{a}\left\{(1-x)^3 + \frac{3(1-x)^2}{a} + \frac{6(1-x)}{a^2} + \frac{6}{a^3}\right\}e^{ax} + \\ + \tfrac{1}{2}(1-\Delta^b) + \frac{2\Delta^b}{a}\left\{1 + \frac{3}{a} + \frac{6}{a^2} + \frac{6}{a^3}\right\} \qquad (2.3\text{-}4)$$

and

$$T_1 = (1-\Delta^b)^2\left\{-\tfrac{1}{2}(1-x)^4 - \frac{(1-x)^3}{a} + \frac{3(1-x)^2}{a^2} - \frac{6(1-x)}{a} + \frac{6}{a^4}\right\} + \\ - \tfrac{3}{2}\Delta^b(1-\Delta^b)(1-x)^4 e^{ax} + \\ + \Delta^{b2}\left\{-\tfrac{1}{2}(1-x)^4 + \frac{(1-x)^3}{a} + \frac{3(1-x)^2}{a^2} + \frac{6(1-x)}{a^3} + \frac{6}{a^4}\right\}e^{2ax} + \\ + \left\{(1-\Delta^b)^2\left(\frac{1}{a} - \frac{3}{a^2} + \frac{6}{a^3} - \frac{6}{a^4}\right) + \tfrac{1}{2} + \tfrac{1}{2}\Delta^b(1-\Delta^b) + \right. \\ \left. - \Delta^{b2}\left(\frac{1}{a} + \frac{3}{a^2} + \frac{6}{a^3} + \frac{6}{a^4}\right)\right\} e^{ax} \qquad (2.3\text{-}5)$$

The value at $r \to \infty$ of the just computed functions may prove to be particularly useful. These value are approximated by:

for Re_v^b up to 5:

$$P_1(\infty) = \frac{1}{2} - \Delta^b\left[1 + \frac{a}{10} + \frac{a^2}{60} + \frac{a^3}{420} + \cdots\right]$$

$$T_1(\infty) = e^a\left\{1 + (1-\Delta)^2\left(-\frac{a}{20} + \frac{a^2}{120} - \frac{a^3}{480} + \cdots\right) + \Delta^2\left(\frac{a}{20} + \frac{a^2}{120} + \frac{a^3}{480} \cdots\right)\right\}$$

and for large Re_v^b:

$$P_1(\infty) = \frac{1}{2}(1-\Delta^b) - \frac{12\Delta^b}{a^4}e^a$$

$$T_1(\infty) = \left\{\frac{1}{2} + \frac{1}{2}\Delta^b(1-\Delta^b)\right\}e^a + \frac{6}{a^4}\Delta^{b^2}e^{2a}$$

The results of the calculation show that when the droplet becomes small, the pressure at the drop $p^*(R)$ is generally higher than the pressure at infinity $p^*(\infty)$, since $p^*(\infty)/p^*(R) = p(\infty) = 1+K.Ma^2.p_1(\infty)$. Consequently the temperature at the droplet $T^*(R)$ will be higher than its boiling point T^*_b corresponding to $p^*(\infty)$, and the driving force for heat transfer is lowered. Therefore a decrease in evaporation rate is expected.

However, when the droplet approaches its critical temperature and the latent heat of vaporization becomes small (or Δ^b becomes small), the reverse behavior is observed. This is due to the fact that when Δ^b becomes small, the gradients in temperature become small and the vapor density becomes constant throughout the domain. For such a system the viscous force counteracting

the radial flow tends to become very small. The only effect left influencing the pressure is the kinetic effect. Therefore the pressure is lowered at the droplet surface and so is the temperature.

In order to compute the corrected value of Re_v, a suitable form of the thermodynamic relationship between temperature and pressure at the droplet surface is used:

$$p(\infty) = \frac{p^*(\infty)}{p^*(R)} = e^{\left\{-\frac{\Delta \hat{H}^*}{\mathcal{R}^* T_b^*} + \frac{\Delta \hat{H}^*}{\mathcal{R}^* T^*(R)}\right\}} \approx 1 + \frac{K}{K-1}\Delta\left(1-\frac{1}{\tau}\right) = 1 + \frac{K}{K-1}\Delta^b(\tau-1)$$

where $\tau = T_b^*/T^*(R)$ and T_b^* is the boiling point of the liquid at $p^*(\infty)$. If the surface tension effects cannot be disregarded, Δ should be replaced by Δ' again such that $p(\infty) = 1 + \frac{K}{K-1}\left\{\Delta' - \Delta/\tau\right\}$. This effect is once again neglected. Since $p(\infty) = 1 + KMa^2 p_1(\infty)$ it follows that:

$$\Delta^b(\tau-1) = (K-1)\,Ma^2\,p_1(\infty)$$

Furthermore

$$T(\infty) = \theta^b\tau = 1 - \Delta^b\tau + \Delta^b\tau\, e^{Re_v Pr} + (K-1)\,Ma^2\,T_1(\infty)$$

where θ^b equals the ratio of the temperature at infinity and the boiling point temperature at the applied pressure, $\theta^b = T^*(\infty)/T^*_b$

substracting from the above equation

$$\theta^b\tau = \tau - \Delta^b\tau + \Delta^b\tau\, e^{Re_v^b Pr} \longrightarrow$$

$$Re_v = Re_v^b - \frac{(K-1)}{\Delta^b \cdot Pr}\,Ma^2\, e^{-Re_v^b Pr}\left\{T_1(\infty) - \frac{p_1(\infty)}{\Delta}\right\}$$

Since $Ma = Re_v^b / \left(\frac{\rho^*(R)\,v_s^*(R)\,R^*}{\mu^*}\right) + \mathcal{O}(Ma^2)$ and $\mu^* = \frac{1}{3}\rho^*(R)\,v_s^*(R)\,\lambda^*(R)$, with $\lambda^*(R)$ being the mean free path

of the vapor molecules at the droplet surface, the equation can be rewritten in its final form:

$$\frac{Re_v}{Re_v^b} = 1 - \frac{(\kappa - 1)\, C_w}{(R^*/\lambda^*(R))^2} \qquad (2.3\text{-}6)$$

It should be noted that here the value of the viscosity at the droplet surface is used. This value should be used also in the application of the above expression to be consistent.

The coefficient C_w is just a function of Re_v^b and Δ^b, because $Pr = \frac{3}{4}$ in this derivation. With the use of equations (2.3-4 and 2.3-5) C_w can be expressed for small and moderate values of Re_v^b:

$$C_w = \frac{4}{27}\,\frac{Re_v^b}{\Delta^b}\cdot\left[1 + (1-\Delta^b)^2\left\{-\frac{\frac{3}{4}Re_v^b}{20} + \frac{(\frac{3}{4}Re_v^b)^2}{120} - \frac{(\frac{3}{4}Re_v^b)^3}{840}\right\} + \right.$$
$$+ \Delta^{b^2}\left\{\frac{\frac{3}{4}Re_v^b}{20} + \frac{(\frac{3}{4}Re_v^b)^2}{120} + \frac{(\frac{3}{4}Re_v^b)^3}{840}\right\} +$$
$$\left. + \left\{1 + \frac{\frac{3}{4}Re_v^b}{10} + \frac{(\frac{3}{4}Re_v^b)^2}{60} + \frac{(\frac{3}{4}Re_v^b)^3}{420}\right\} e^{-\frac{3}{4}Re_v^b} - \frac{e^{-\frac{3}{4}Re_v^b}}{2\Delta^b}\right] \qquad (2.3\text{-}7)$$

for Re_v^b large (and $\Delta^b > e^{-\frac{3}{4}Re_v^b}$) C_w reduces to:

$$C_w = \frac{4}{27}\,\frac{Re_v^b}{\Delta^b}\cdot\left[\frac{6\,\Delta^{b^2}}{(\frac{3}{4}Re_v^b)^4}\cdot e^{\frac{3}{4}Re_v^b}\right] \qquad (2.3\text{-}8)$$

when $\Delta^b=1$, some values for C_w are: $Re_v^b=0, C_w=0$; $Re_v^b=1, C_w=.2$; $Re_v^b=10, C_w=5$.

Apparently when the droplet is evaporating slowly (small Re_v^b) no deviation from the linear law is noticed, unless the droplet size diminishes to near molecular dimensions. Clearly the surface tension effects should be taken into account in this case.

The rapidly evaporating droplet, however, the correction becomes appreciable as soon as its radius is of the order of the mean free path of the vapor molecules. The evaporation law should be corrected:

$$\dot{M} = \kappa^* \left(1 - \frac{(\kappa - 1)\, C_w}{(R^* / \lambda^*(R))} \right) R^* \qquad (2.3\text{-}9)$$

From this result can be seen, that when the droplet becomes small, the evaporation rate of the droplet generally decreases. Near its critical point, however, a small droplet tends to evaporate spontaneously.

2-4. Corrections for Evaporation in a Convective Environment

2-4.1 Preliminary considerations.

Although the evaporation of a droplet in the convective environment of its own vapor may appear to be an entirely different phenomenon than the evaporation in a stagnant atmosphere, the solution for the stagnant case can be used as a starting point for the description of this process. However, this treatment has to be limited to very small values of the Reynolds number, "Re_c", characterizing the forced convective flow field:

$$Re_c = \frac{\rho^*(\infty)\, V^*(\infty)\, R^*}{\mu^*}$$

As was seen previously for a rapidly evaporating droplet, the Reynolds number, "Re_v", which describes the evaporation, is of order unity, or may even be larger and, although forced convective flow dominates at infinity, the mass flux due to evaporation overrides the forced field near the surface of the droplet, when $Re_c \ll Re_v$.

A first estimate of the behavior of the droplet can be obtained following a procedure, which provides an approximation of the entire flow field by assuming all forced convective effects to be of order of a small parameter γ. γ is the ratio of the vapor velocity at infinity to the averaged vapor velocity at the droplet surface:

$$\gamma = \underline{V}^*(\infty) \,/\, \overline{\underline{V}^*(R)}$$

Following this procedure a special form is assumed for the velocity, which can be represented schematically:

$$u = u^* / \overline{u^*(R)} = u_0(r) + \gamma . u_I(r, \theta)$$

$$v = v^* / \overline{u^*(R)} = \gamma . v_I(r, \theta)$$

where u and v to denote the radial and tangential component respectively. In this expression, $u_0(r)$ is the velocity derived for the evaporation in a stagnant atmosphere. For simplicity the drop is thought to be large here.

Very close to the drop $u_0(r)$ is very much greater than $\gamma u_I(r, \theta)$. Since $u_0(r)$ is of order unity there and γ is assumed to be much smaller than unity . Similarly $u_0(r)$ is very much greater than $\gamma v_I(r, \theta)$ near to the surface. Far away from the droplet, however, $u_I(r, \theta)$ and $v_I(r, \theta)$ are of order unity, while $u_0(r)$ approaches zero at infinity, therefore the forced flow dominates no matter how small γ is. Because all gradients have vanished at infinity, the influence of this effect on the overall solution can be neglected for a sufficiently small value of γ. This procedure clearly is an approximation and in no way a straight forward perturbation due to the apparent singular nature of the problem.

This procedure of approximation is preferable to a numerical analysis of the general problem, because of the complexity which would be inherent in the numerical treatment mainly due to the large number of nonlinear terms in the equations.

2-4.2. Description of the problem.

An initial consideration of the equations is already most revealing. When the nondimensionalization is carried out in the same way as above by dividing the quantities by their corresponding averaged value at the droplet surface, the equations reduce thus: the continuity equation can be written as:

$$\nabla \cdot \rho \underline{v} = 0$$

The equation of motion can be written as:

$$Re_v \nabla p = K\, Ma^2 \left\{ Re_v \cdot (\text{convective terms}) + (\text{viscous terms}) \right\}$$

The equation of thermal energy can be written as:

$$Re_v\, Pr\, \rho \underline{v} \cdot \nabla T = \nabla^2 T + (\text{terms of order } Ma^2)$$

and the equation of state is not changed of course:

$$p = \rho T$$

In writing the equations in this form it is assumed that $p^*(R)$, $T^*(R)$ and $\rho^*(R)$ are uniform over the droplet surface. It is easily seen that this holds true up to order γ, because, when the velocity is assumed to be of the form (which includes the possibility of the drop becoming small):

$$u = u_0(r) + Ma^2 . u_1(r) + \gamma u_I(r,\theta) \qquad (2.4\text{-}1)$$

$$v = \gamma v_I(r,\theta) \qquad (2.4\text{-}2),$$

the temperature and the density have to be of the form:

$$T = T_0(r) + (K-1) Ma^2 T_1(r) + \gamma T_I(r,\theta) \qquad (2.4\text{-}3)$$

$$\rho = \rho_0(r) + Ma^2 \rho_1(r) + \gamma \rho_I(r,\theta) \qquad (2.4\text{-}4).$$

However the pressure should be of the form:

$$p = p_0(r) + KMa^2 p_1(r) + KMa^4 p_2(r) + KMa^2 \gamma p_I(r,\theta) \ldots \qquad (2.4\text{-}5)$$

because there are no terms in the equation of motion, which are not multiplied by a factor Ma^2 except for the pressure gradient term.

It should be noted that it was not necessary to compute $u_1(r)$ and $\varrho_1(r)$ for the treatment of the evaporation of a small droplet in a stagnant atmosphere. Both functions are implicitly known already, however, and can easily be found by applying the equation of state:

$$p = p_0 + KMa^2 p_1 = \varrho T = \varrho_0 T_0 + Ma^2(\varrho_1 T_0 + (K-1)\cdot \varrho_0 T_1)$$

or $$\frac{\varrho_1}{\varrho_0} = K\frac{p_1}{p_0} - (K-1)\frac{T_1}{T_0}$$

and by applying the continuity equation:

$$r^2 \varrho u = r^2(\varrho_0 + Ma^2\varrho_1)(u_0 + Ma^2 u_1) = 1$$

or $$\frac{u_1}{u_0} = -\frac{\varrho_1}{\varrho_0}$$

Furthermore, $p_2(r)$ is mentioned to be complete, it is computed from the equation of motion for the stagnant case (2.3-3a) after the appropriate terms for ϱ_1 and u_1 are introduced.

Although the pressure gradient in the equation of motion, $(Re / KMa^2)\ \nabla p$, is indeed of the same order as the convective and viscous terms, the pressure itself is not significantly influenced by the forced convective flow field because this influence is only of order $Ma^2\gamma$, which is negligible. Therefore, the pressure is the same as in the case of evaporation in stagnant atmosphere as is the vapor pressure at the droplet surface. Since the temperature of the droplet is only a

function of the vapor pressure, this temperature is also essentially uniform over the droplet surface and equal to the temperature of the same droplet evaporating in stagnant atmosphere. The same is true of the density of the vapor at the droplet surface.

Keeping in mind the axial symmetry of the system and choosing the angle to be zero ($\theta = 0$) at the backside of the droplet and $\theta = \pi$ at the stagnation point, the equations can be now written in their elaborate form: The continuity equation is:

$$\frac{1}{r^2}\frac{\partial}{\partial r}(r^2 \rho u) + \frac{1}{r \sin\theta}\frac{\partial}{\partial \theta}(\sin\theta\, \rho v) = 0 \qquad (2.4\text{-}6).$$

The radial component of the equation of motion can be written as:

$$\frac{Re_v}{K Ma^2}\cdot\frac{\partial p}{\partial r} = -Re_v\left\{\rho u\frac{\partial u}{\partial r} + \rho\frac{v}{r} - \rho\frac{v^2}{r}\right\} + -\left[\frac{1}{r^2}\frac{\partial}{\partial r}(r^2\tau_{rr}) + \frac{1}{r\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta\,\tau_{r\theta}) - \frac{\tau_{\theta\theta}+\tau_{\phi\phi}}{r}\right] \qquad (2.4\text{-}7)$$

- tangentiel component -

$$\frac{Re_v}{K Ma^2}\cdot\frac{1}{r}\frac{\partial p}{\partial\theta} = -Re_v\left\{\rho u\frac{\partial v}{\partial r} + \rho\frac{v}{r}\frac{\partial v}{\partial\theta} + \rho\frac{uv}{r}\right\} + -\left[\frac{1}{r^2}\frac{\partial}{\partial r}(r^2\tau_{r\theta}) + \frac{1}{r\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta\,\tau_{\theta\theta}) + \frac{\tau_{r\theta}}{r} - \frac{\cot\theta}{r}\tau_{\phi\phi}\right] \qquad (2.4\text{-}8)$$

where

$$\tau_{rr} = -\left[\frac{4}{3}\frac{\partial u}{\partial r} - \frac{4}{3}\frac{u}{r} - \frac{2}{3}\frac{1}{r}\frac{\partial v}{\partial r} - \frac{2}{3}\frac{v}{r}\cot\theta\right]$$

$$\tau_{\theta\theta} = -\left[-\frac{2}{3}\frac{\partial u}{\partial r} + \frac{2}{3}\frac{u}{r} + \frac{4}{3}\frac{1}{r}\frac{\partial v}{\partial\theta} - \frac{2}{3}\frac{v}{r}\cot\theta\right]$$

$$\tau_{\phi\phi} = -\left[-\frac{2}{3}\frac{\partial u}{\partial r} + \frac{2}{3}\frac{u}{r} - \frac{2}{3}\frac{1}{r}\frac{\partial v}{\partial\theta} + \frac{4}{3}\frac{v}{r}\cot\theta\right]$$

$$\tau_{r\theta} = -\left[\frac{\partial v}{\partial r} - \frac{v}{r} + \frac{1}{r}\frac{\partial u}{\partial\theta}\right] \qquad (2.4\text{-}9),$$

and the stress tensor components are made nondimensional by:

$$\tau = \tau^* R^* / \mu^* \overline{u^*(R)}$$

The equation of thermal energy is:

$$Re_v\, Pr \left\{ \rho u \frac{\partial T}{\partial r} + \rho v \frac{\partial T}{\partial \theta} \right\} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial T}{\partial r}\right) + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta \frac{\partial T}{\partial \theta}\right) +$$

$$+ \frac{\kappa - 1}{\kappa} Re_v\, Pr \left\{ u \frac{\partial p}{\partial r} + v \frac{\partial p}{\partial \theta} \right\} + (\kappa - 1)\, Ma^2\, Pr\, \Phi \qquad (2.4\text{-}10)$$

where Φ is the dissipation function:

$$\Phi = -\left(\underline{\underline{\tau}} : \nabla \underline{v} \right) \qquad (2.4\text{-}11)$$

The equation of State still is: $p = \rho T$.

The equations can now be reduced by replacing the variables with their expansions, equations (2.4-1) to (2.4-5). The terms, which are functions of r only, can be cancelled because these are solutions for the problem of evaporation in a stagnant atmosphere. This is illustrated below for the continuity equation:

$$\cancel{\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \rho_0 u_0\right)}^{\,0} + \frac{Ma^2}{r^2}\frac{\partial}{\partial r}\left(r^2 \rho_1 u_0 + r^2 \rho_0 u_1\right)^{\,0}$$

$$+ \gamma \left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \rho_0 u_I + r^2 \rho_I u_0\right) + \frac{1}{r \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\, \rho_0 v_I\right) \right] + \cdots = 0 \qquad (2.4\text{-}12)$$

or

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \rho_0 u_I\right) + \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \rho_I u_0\right) + \frac{1}{r \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\, \rho_0 v_I\right) = 0$$

The simplification of the equation of motion is no more difficult. The pressure gradient in the radial direction can be written:

$$\frac{Re_v}{\kappa Ma^2}\frac{\partial p}{\partial r} = Re_v \left\{ \frac{dp_1}{dr} + Ma^2 \frac{dp_2}{dr} + \gamma \frac{\partial p_I}{\partial r} + \cdots \right\}$$

The term containing p_1 cancels the convective and viscous terms containing ρ_0 and u_0 only. The term containing p_2 cancels the convective and viscous terms involving ρ_1 and u_1 just once, together with ρ_0 and u_0. Terms of order (γ^2) and $(Ma^2\gamma)$

are neglected, and the result can be written:

$$Re_v \frac{\partial P_I}{\partial r} = -Re_v \left\{ \rho_o u_o \frac{\partial u_I}{\partial r} + \rho_o u_I \frac{du_o}{dr} + \rho_I u_o \frac{du_o}{dr} \right\} + \\ -\left[\frac{1}{r^2}\frac{\partial}{\partial r}(r^2 \tau^{\gamma}_{rr}) + \frac{1}{r\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta\, \tau^{\gamma}_{r\theta}) - \frac{\tau^{\gamma}_{\theta\theta} + \tau^{\gamma}_{\phi\phi}}{r} \right] \qquad (2.4\text{-}14)$$

The pressure gradient in the tangentiel direction can be written:

$$\frac{Re_v}{\kappa Ma^2}\frac{1}{r}\frac{\partial P}{\partial\theta} = Re_v \gamma \frac{1}{r}\frac{\partial P}{\partial\theta} + \cdots$$

and it becomes evident that

$$Re_v \frac{1}{r}\frac{\partial P_I}{\partial\theta} = -Re_v \left\{ \rho_o u_o \frac{\partial v_I}{\partial r} + \frac{\rho_o u_o v_I}{r} \right\} + \\ -\left[\frac{1}{r^2}\frac{\partial}{\partial r}(r^2 \tau^{\gamma}_{r\theta}) + \frac{1}{r\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta\, \tau^{\gamma}_{\theta\theta}) + \frac{\tau^{\gamma}_{r\theta}}{r} - \frac{\cot\theta}{r}\tau^{\gamma}_{\phi\phi} \right] \qquad (2.4\text{-}15)$$

where

$$\tau^{\gamma}_{rr} = -\left[\frac{4}{3}\frac{\partial u_I}{\partial r} - \frac{4}{3}\frac{u_I}{r} - \frac{2}{3}\frac{1}{r}\frac{\partial v_I}{\partial\theta} - \frac{2}{3}\frac{v_I}{r}\cot\theta \right]$$

$$\tau^{\gamma}_{\theta\theta} = -\left[-\frac{2}{3}\frac{\partial u_I}{\partial r} + \frac{2}{3}\frac{u_I}{r} + \frac{4}{3}\frac{1}{r}\frac{\partial v_I}{\partial\theta} - \frac{2}{3}\frac{v_I}{r}\cot\theta \right]$$

$$\tau^{\gamma}_{\phi\phi} = -\left[-\frac{2}{3}\frac{\partial u_I}{\partial r} + \frac{2}{3}\frac{u_I}{r} - \frac{2}{3}\frac{1}{r}\frac{\partial v_I}{\partial\theta} + \frac{4}{3}\frac{v_I}{r}\cot\theta \right]$$

$$\tau^{\gamma}_{r\theta} = -\left[\frac{\partial v_I}{\partial r} - \frac{v_I}{r} + \frac{1}{r}\frac{\partial u_I}{\partial\theta} \right] \qquad (2.4\text{-}16)$$

Following the same procedure, for thermal energy equation, cancelling the terms, which are functions of r only and neglecting terms of $\mathcal{O}(\gamma^2)$, $\mathcal{O}(Ma^2\gamma)$ and higher, this simplified equation is derived:

$$Re_v Pr \left[\rho_o u_o \frac{\partial T_I}{\partial r} + \rho_o u_I \frac{dT_o}{dr} + \rho_I u_o \frac{dT_o}{dr} \right] = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial T_I}{\partial r} \right) + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta \frac{\partial T_I}{\partial\theta} \right) \qquad (2.4\text{-}13)$$

The equation of state simply reduces to:

$$P_o + Ma^2 P_1 + \cdots = \rho_o T_o + Ma^2(\rho_1 T_o + \rho_o T_1) + \gamma(\rho_I T_o + \rho_o T_I) + \cdots$$

or

$$\rho_I = -\rho_o \frac{T_I}{T_o} \qquad (2.4\text{-}17)$$

A salient feature of the problem is now apparent: the approximation for evaporation in the forced flow field and the perturbation for the evaporation of a small droplet may be thought to be superimposed. A solution for the convective problem derived for a large droplet is valid also for a small droplet,

substituting the appropriate values of the characteristic numbers. Furthermore it should be noted that ρ_0, u_0 and T_0 are known functions (of r only):

$$\rho_0 = \frac{1}{T_0} \; ; \; u_0 = \frac{T_0}{r^2} \quad \text{and} \quad T_0 = 1 - \Delta\left(1 - e^{Re_v Pr\left(1-\frac{1}{r}\right)}\right)$$

It is appropriate to state the boundary conditions for the correction terms at this point: For r becoming infinitely large: $T^* = T^*(\infty)$, $p^* + p^*(\infty)$, $u^* = |\underline{v}^*(\infty)| \cdot \cos\theta$ and $v^* = -|\underline{v}^*(\infty)| \cdot \sin\theta$

giving B.C. at r = 1 :

$$T_I(\infty, \theta) = 0$$
$$p_I(\infty, \theta) = 0$$
$$u_I(\infty, \theta) = \cos\theta$$
$$v_I(\infty, \theta) = -\sin\theta$$

It was seen previously that the temperature at the droplet surface is not affected significantly, by the presence of the forced convective field. Thus:

$$\text{at } r = 1 \qquad T_I(1, \theta) = 0$$

Furthermore the viscosity of the droplet is much higher than the viscosity of the vapor, so that the tangentiel velocity has to vanish at the droplet surface:

$$v_I(1, \theta) = 0$$

The last boundary condition arises from the consideration that the radial heat flux has to be continuous at the droplet surface or:

$$\dot{M}^* \hat{\mathcal{H}}^*_{(liquid)} = -4\pi R^{*2} \rho^*(R) u^*(R) \left\{ \hat{\mathcal{H}}^*(R) + \frac{1}{2} u^2 \right\} + 4\pi R^{*2} \left(\frac{dT^*}{dr^*} \right)_{R^*} - 4\pi R^{*2} \tau^*_{rr}(R) u(R)$$

where H* is the enthalpy per unit mass and $\dot{M} = -4\pi R^{*2} \rho^*(R) u^*(R)$.

Note that no terms containing v* enter the equation, since v* equals zero at the surface, as was already seen. Cancelling terms and neglecting those of $\mathcal{O}(Ma^2\gamma)$ and higher order, the equation can be written in its nondimensionalized form:

$$Re_v \, Pr \, \Delta \, u_I(r,\theta)\Big|_{r=1} = \frac{\partial T_I}{\partial r}\Big|_{r=1}$$

If the surface tension effects should be taken into account, Δ should be replaced by Δ'.

2-4.3. A first step towards solution.

In the investigation of the form of the equations and boundary conditions, it becomes apparent that the solution should be of the form:

$$\begin{aligned} p_I &= e(r)\cos\theta \\ T_I &= f(r)\cos\theta \\ u_I &= g(r)\cos\theta \\ v_I &= -h(r)\sin\theta \qquad (2.4\text{-}18), \end{aligned}$$

because in this form the solutions satisfy the equations (2.4-12) to (2.4-17) as well as the boundary conditions. Consequently the θ dependence is eliminated from these equations. A considerable simplification of the equations is obtained, by a change of variable, $x = 1 - \frac{1}{r}$, and eliminating the density by using of the expression $\rho_I = - T_I / T_0^2$ and denoting $A(x) = \frac{1}{T_0}\frac{dT_0}{dx}$

Substituting the above equations (2.4-18) in the expressions for the components of the stress tensor (2.4-9), these expressions reduce to:

$$\tau_{rr} = -\frac{4}{3}\left[\frac{du_0}{dr} - \frac{u_0}{r} + \gamma\cos\theta\left\{\frac{dg}{dr} - \frac{g}{r} + \frac{h}{r}\right\}\right]$$

and $\tau_{\theta\theta} = \tau_{\phi\phi} = -\frac{1}{2}\tau_{rr}$

$$\tau_{r\theta} = \gamma \sin\theta \left[\frac{dh}{dr} - \frac{h}{r} + \frac{g}{r}\right]$$

or for the part which remains in the equations approximating the convective flow field:

$$\tau^{\gamma}_{rr} = -\frac{4}{3}\cos\theta \left\{(1-x)^2 g' - (1-x)g + (1-x)h\right\}$$

and $\tau^{\gamma}_{\theta\theta} = \tau^{\gamma}_{\phi\phi} = -\frac{1}{2}\tau^{\gamma}_{rr}$

$$\tau^{\gamma}_{r\theta} = \sin\theta \left\{(1-x)^2 h' - (1-x)h + (1-x)g\right\} \tag{2.4-19}$$

where primes denote derivatives with respect to x.

From the tangentiel component of the equation of motion, an expression for the pressure is found:

$$Re_v \frac{\partial p_I}{\partial \theta} = -Re_v \sin\theta \left\{-(1-x)^3 h' - (1-x)^2 h\right\} + \\ -\sin\theta \left\{(1-x)^3 h'' - \frac{8}{3}(1-x)h + \frac{1}{3}(1-x)^2 g' + \frac{8}{3}(1-x)g\right\} \tag{2.4-20}$$

which is readily integrated with applicational the boundary condition: B.C. at x = 1: $p_I = 0$

$$Re_v\, p_I = Re_v \cos\theta \left\{-(1-x)^3 h' - (1-x)^2 h\right\} + \\ +\cos\theta \left\{(1-x)^3 h'' - \frac{8}{3}(1-x)h + \frac{1}{3}(1-x)^2 g' + \frac{8}{3}(1-x)g\right\} \tag{2.4-21}$$

Using this expression to eliminate p_I, the equation of motion can be written as:

$$Re_v \left[(1-x)^2 g' + \left\{(1-x)^2 A(x) - 2(1-x)\right\} g + \left\{2(1-x)^3 - (1-x)^4 A(x)\right\} f + \\ -(1-x)^3 h'' + 2(1-x)^2 h' + 2(1-x)h\right] + \\ +\left[(1-x)^3 h''' - 3(1-x)^2 h'' - 2(1-x)h - 2h - (1-x)^2 g'' + 2(1-x)g' + 2g\right] = 0 \tag{2.4-22}$$

The continuity equation reduces to:

$$-(1-x)^2 f' + (1-x)^2 A(x) f + g' - A(x) g + \frac{2}{(1-x)} g - \frac{2}{(1-x)} h = 0 \tag{2.4-23}$$

The thermal energy equation also reduces to:

$$f'' - \frac{2}{(1-x)^2} f + Re_v Pr A(x) f - Re_v Pr f' - \frac{Re_v Pr A(x)}{(1-x)^2} g = 0 \tag{2.4-24}$$

where

$$A(x) = \frac{Re_v Pr \Delta e^{Re_v Pr x}}{1 - \Delta + \Delta e^{Re_v Pr x}} \tag{2.4-25}$$

This is a set of three linear differential equations with varying coefficients. The boundary conditions can be stated:

at $x = 0$	$f = 0$	; at $x = 1$:	$f = 0$
	$f = Re_v Pr \Delta . g$		$g = 1$
	$h = 0$		$h = 1$

Although this set of equations still remains to be solved, a preliminary conclusion can already be drawn from the form, the solution must take. The "Convective" contribution to the radial velocity, averaged over the droplet surface, equals zero, because $u_I = g \cdot \cos\theta$. Therefore, this term does not contribute to the total vapor flow evaporating from the surface, and the total rate of change of the mass of the droplet is not affected by the presence of the forced convective flow field.

3. SOLUTION FOR THE EVAPORATION IN CONVECTIVE ENVIRONMENT

3.1 Polynomial Approximation.

The simultaneous equations, are difficult to solve analytically, especially because of the variation of the coefficients. But because it is desired, to provide some insight into the behavior of the solution, a polynomial approximation of the solution is developped.

The functions f, g and h can be expanded in a Taylor series around the point x = 0 (the surface of the drop) they are written in the form:

$$f = \sum_{n=0}^{\infty} \frac{f^{(n)}(0)}{n!} x^n \,, \quad g = \sum_{n=0}^{\infty} \frac{g^{(n)}(0)}{n!} x^n \,, \quad h = \sum_{n=0}^{\infty} \frac{h^{(n)}(0)}{n!} x^n$$

The derivatives used in these expressions can be found directly by the evaluation of these equations at x = 0. In this manner f''(0) is found from the thermal energy equation, g'(0) from the continuity equation and h'''(0) from the equation of motion. The higher derivatives are found succesively by taking the derivative of the respective equations and by evaluation of the result at x=0. The derivatives found in this fashion contain three undetermined constants, which can be computed later on by applying the boundary condition at x = 1. ($r \to \infty$) Denote: $a = Re_v \, Pr$ and $b = Re_v$. It is found:

$$f(0) = 0$$
$$f'(0) = a\Delta \cdot g(0)$$
$$f''(0) = 2a^2\Delta \cdot g(0)$$
$$f'''(0) = (2a\Delta + 3a^3\Delta)\, g(0)$$
$$f^{IV}(0) = (8a\Delta + 6a^2\Delta + 4a^4\Delta)\, g(0) + 2a^2\Delta\, h'(0)$$

and

$$g(0) = g(0)$$
$$g'(0) = (2a\Delta - 2)\, g(0)$$
$$g''(0) = (2 - 8a\Delta + 3a^2\Delta)\, g(0) + 2h'(0)$$
$$g'''(0) = (14a\Delta - 18a^2\Delta + 4a^3\Delta)\, g(0) + 2a\Delta h'(0) + 2h''(0)$$
$$g^{IV}(0) = [8 - 32a\Delta + 48a^2\Delta - 32a^3\Delta + 5a^4\Delta + b(8 - 6a\Delta)] \cdot g(0) + [16 + 2a\Delta - 8b - 2b^2]\, h'(0) + [16 + 4b + b^2]\, h''(0)$$

and

$$h(0) = 0$$
$$h'(0) = h'(0)$$
$$h''(0) = h''(0)$$
$$h'''(0) = [4 - 12a\Delta + 3a^2\Delta + b(4 - 3a\Delta)]\, g(0) + [4 - 2b]\, h'(0) + [3 + b]\, h''(0)$$
$$h^{IV}(0) = [(16 - 26a\Delta - 12a^2\Delta + 4a^3\Delta) + b(16 - 12a\Delta - a^2\Delta) + b^2(4 - 3a\Delta)]\, g(0) + [16 + 2a\Delta - 8b - 2b^2]\, h'(0) + [16 + 4b + b^2]\, h''(0)$$

In the above expressions g(0), h'(0), h''(0) are still undetermined. When f, g and h are approximated by polynomials of the third degree, they are written:

$$f = f(0) + \frac{f'(0)}{1!} \cdot x + \frac{f''(0)}{2!} x^2 + \frac{f'''(0)}{3!} x^3$$

$$g = g(0) + \frac{g'(0)}{1!} x + \frac{g''(0)}{2!} x^2 + \frac{g'''(0)}{3!} x^3$$

$$h = h(0) + \frac{h'(0)}{1!} x + \frac{h''(0)}{2!} x^2 + \frac{h'''(0)}{3!} x^3$$

When the boundary conditions at infinity are applied: f(1) = 0, g(1) = 1, h(1) = 1 it is found, that

$$g(0) = 0, \quad h'(0) = \frac{12 + 3b}{8 + 5b + 6a\Delta + ab\Delta}, \quad h''(0) = \frac{-12 + 6b + 6a\Delta}{8 + 5b + 6a\Delta + ab\Delta}$$

After substitution of the results, the equations read:

$$f \equiv 0 \qquad (3.1\text{-}1)$$

$$g = \frac{12+3b}{8+5b+6a\Delta+ab\Delta}\,x^2 + \frac{-4+2b+6a\Delta+ab\Delta}{8+5b+6a\Delta+ab\Delta}\,x^3$$

$$h = \frac{12+3b}{8+5b+6a\Delta+ab\Delta}\,x + \frac{-6+3b+3a\Delta}{8+5b+6a\Delta+ab\Delta}\,x^2 + \frac{2-b+3a\Delta+ab\Delta}{8+5b+6a\Delta+ab\Delta}\,x^3$$

Clearly, this is not a very close approximation, since the temperature profile is approximated in a very elimentary fashion. Note that for $Re_v=0$ (thus a=0, b=0) the solution reduces to the Stokes solution:

$$g = \frac{3}{2}x^2 - \frac{1}{2}x^3 = 1 - \frac{3}{2}\left(\frac{1}{r}\right) + \frac{1}{2}\left(\frac{1}{r}\right)^3 \qquad (3.1\text{-}2)$$

$$h = \frac{3}{2}x^2 - \frac{3}{4}x^2 + \frac{1}{4}x^3 = 1 - \frac{3}{4}\left(\frac{1}{r}\right) - \frac{1}{4}\left(\frac{1}{r}\right)^3$$

It is convenient, at this point, to compute the drag force acting on the drop, the result being expressed in terms of the friction factor:

$$C_D = \frac{F^*}{\frac{1}{2}\rho^*(\infty)\,|v^*(\infty)|^2 \cdot \pi R^{*2}} \quad , \quad Re_c\, C_D = \frac{2\,F^*}{\pi \mu^* R^* |v^*(\infty)|}$$

where F* is the total force acting on the droplet in the direction of the forced convective flow. F* can be found directly by integration of the equation of motion. F* equals the total rate of change of the impuls of the drop in the direction of the forced convective flow:

$$F^* = \iiint_{V_{drop}} \frac{\partial}{\partial t}(\rho^* v^*)_z \, dV^*_{drop} = \iint_{S_{drop}} -\left\{[\underline{n}^* \cdot \rho^* \underline{v}^* \underline{v}^*] + \underline{n}^*_z p + [\underline{n}^* \cdot \underline{\tau}^*]_z\right\} dS_{drop}$$

The last integral is evaluated over the surface of the droplet, $\underline{n}$ denotes the normal (directed outward), and z denotes the direction

of the forced convective flow. This expression can be rewritten thus:

$$F^* = \int_0^{2\pi}\int_0^{\pi}\left\{\left(-\rho^*(R)\,u^*(R)^2 - p^*(R) - \tau_{rr}^*(R)\right)\cos\theta + \tau_{r\theta}^*(R)\sin\theta\right\}R^{*2}\sin\theta\,d\theta\,d\phi$$

or in its nondimensional form:

$$F^* = 2\pi\mu^* R^* u^*(R)\int_0^{\pi}\left\{\left(-Re_v\,\rho(R)\,u(R)^2 - \frac{Re_v}{Km^2}\,p(R) - \tau_{rr}(R)\right)\cos\theta + \tau_{r\theta}(R)\sin\theta\right\}\sin\theta\,d\theta$$

When in the above equation the appropriate expressions (2.4-1) to (2.4-5) are substituted and it is noted that the terms which are constant over the droplet surface do not contribute to the integral, and neglecting the term of order γ^2, it is found that:

$$C_D \cdot Re_c = \frac{4}{\gamma}\int_0^{\pi}\left\{\left(-Re_v \cdot 2\gamma\, u_I(0) - Re_v\,\gamma\, p_I(0) - \gamma\,\tau_{rr}^{\gamma}(0)\right)\cos\theta + \gamma\,\tau_{r\theta}(0)\sin\theta\right\}\sin\theta\,d\theta$$

or

$$C_D \cdot Re_c = -\frac{8}{3}\Big[2\,Re_v\,g(0) - Re_v\,h'(0) + h''(0) + \frac{1}{3}g'(0) + \frac{8}{3}g(0) + \\ - \frac{4}{3}\left(g'(0) - g(0)\right)\Big] + \frac{16}{3}\left[h'(0) + g(0)\right] \qquad (3.1\text{-}3)$$

For the approximation of the solution by the polynomial of the third degree, it is an easy matter to find the friction coefficient. Note that $g(0)$ and $g'(0)$ are zero:

$$C_D\,Re_c = \frac{8}{3}\left[(2 + Re_v)\,h'(0) - h''(0)\right]$$

or

$$C_D\,Re_c = \frac{8}{3}\cdot\frac{36 + 12\,Re_v + 3\,Re_v^2 - 6\,Re_v\,Pr\,\Delta}{8 + 5\,Re_v + 6\,Re_v\,Pr\,\Delta + Re_v^2\,Pr\,\Delta} \qquad (3.1\text{-}4)$$

When $Re_v = 0$ (Stokes solution), then $c_d \cdot Re_c = 12$, as it should.

Care should be taken not to apply this equation without investigation. Furthermore note that the friction coefficient should even become negative for sufficiently large value of $\Delta = \Delta\hat{H}^*/\hat{c}_p^* \cdot T^*(R)$.

However, it should be kept in mind, that this result is derived from a "solution" which is only a fair approximation of the actual behavior of the droplet.

Polynomial approximation to a higher degree becomes prohibitively complicated due to the large number of terms in the equations. The approximation by fourth degree polynomials will be carried out here up to the point where it is possible to provide some more evidence for the strange behavior of the droplet when Δ becomes large. The same procedure as before is followed. The functions are represented by their truncated Taylor series about $x = 0$.

$$f = f(0) + f'(0).x + \frac{f''(0)}{2}x^2 + \frac{f'''(0)}{6}x^3 + \frac{f^{IV}(0)}{24}x^4$$

$$g = g(0) + g'(0).x + \frac{g''(0)}{2}x^2 + \frac{g'''(0)}{6}x^3 + \frac{g^{IV}(0)}{24}x^4$$

$$h = h(0) + h'(0).x + \frac{h''(0)}{2}x^2 + \frac{h'''(0)}{6}x^3 + \frac{h^{IV}(0)}{24}x^4$$

The boundary conditions at infinity are applied again with $f(1)=0$,

$$h'(0) = -\left(\frac{20}{a} + 15 + 6a + 2a^2\right) g(0) = -C_1 . g(0)$$

with $g(1)=1$,

$$h''(0) = \frac{12}{(8+a\Delta+b)} \cdot \Big[1 - \Big\{\frac{1}{3} - a\Delta + \frac{1}{2}a^2\Delta - \frac{2}{3}a^3\Delta + \frac{5}{24}a^4\Delta + b\left(\frac{1}{3} - \frac{a\Delta}{4}\right) + - \left(\frac{4}{3} + \frac{1}{6}a\Delta + \frac{1}{3}a^2\Delta - \frac{1}{6}a^2\Delta^2 - \frac{1}{6}b\right)C_1\Big\} g(0)\Big]$$

$$= \frac{12}{(8+a\Delta+b)} + C_2 \cdot g(0)$$

and with $h(1)=1$,

$$\Big\{-\left[1 + \frac{1}{6}(4-2b) + \frac{1}{24}(16+2a\Delta-8b-2b^2)\right]C_1 + \left[\frac{1}{2} + \frac{1}{6}(3+b) + \frac{1}{24}(16+4b+b^2)\right]C_2 + \frac{1}{6}(4-12a\Delta+3a^2\Delta) + \frac{1}{24}(16-26a\Delta-12a^2\Delta+4a^3\Delta) + \frac{1}{6}b(4-3a\Delta) + \frac{b}{24}(16-2a\Delta-a^2\Delta) + \frac{b^2}{24}(4-3a\Delta)\Big\} \cdot g(0) =$$

$$= 1 - \frac{12}{8+a\Delta+b}\left[\frac{1}{2} + \frac{1}{6}(3+b) + \frac{1}{24}(16+4b+b^2)\right]$$

When Re_v equals zero, note that $c_1 = \frac{20}{a}$, $c_2 = \frac{40}{a}$ and $g(0) = -\frac{3a}{40}$. Therefore: $h'(0) = \frac{3}{2}$, $h''(0) = -\frac{3}{2}$, $g(0)=0$, and the approximation again reduces to the Stokes solution as it should.

The solution of special interest is that for large Δ, when Δ becomes large, c_1 is not affected, but c_2 approaches $-2a\Delta c_1$. Accordingly:

$$a\Delta\left[\left(-\frac{41}{12}-\frac{2}{3}b-\frac{1}{12}b^2\right)c_1+\left(-\frac{37}{12}-b+\frac{1}{6}a^2-\frac{1}{24}ab-\frac{3}{24}b^2\right)\right]g(0)=1$$

or $-a\Delta \cdot c_3' \cdot g(0) = 1$. Note that c_3' just as c_1 is a positive constant, and for the limit when Δ becomes very large, it is found:

$$g(0)=0\ ,\quad g'(0)=-\frac{2}{c_3'}\ ,\quad h'(0)=0\ ,\quad h''(0)=\frac{2c_1}{c_3'}$$

For the friction factor it is found that:

$$C_D \cdot Re_c = -\frac{8}{3}\left[h''(0)+\frac{1}{3}g'(0)\right] = -\frac{16}{3}\frac{(c_1-1)}{c_3'}$$

which is always negative since $c_1 > 1$.

Clearly the fourth degree polynomial would predict the same result as the third degree polynomial. However, as will be seen both approximations are in distinct disagreement with the numerical results for Δ being large. From the numerical results will be seen, that the "convective" contribution to the temperature, the function f, is monotonously increasing from x=0 to x=1 and drops back to zero suddenly at x=1. Such a function is not easy to approximate with an polynomial expansion around x=0. For cases, where the gradients in the temperature field are large (Δ^* large, Re_v large) the polynomial approximation is gravely in error, since it is not able to represent the temperature profile correctly. In those

cases many more terms should have to be taken into account, but due to the complexity in the expressions this is not feasible.

3.2 Numerical treatment of the problem.

The set of simultaneous equations (2.4-22) to (2.4-24) from which already the angle dependence is eliminated can not be solved numerically by any easy method, because the set consists of three simultaneous ordinary linear differential equations involving higher order derivatives and with split boundary conditions for each of the variables. Careful investigation shows that the set is indeed a sixth order system.

Generally there are several approaches which can be tried. However, a "marching" solution, for instance, will result in excessive trial and error. Direct integration from one end to the other would require that three additional values of the respective functions or their derivatives be known at the starting point (x=0), since there are only three boundary conditions known at either end.

Therefore a "jury" solution method in which the whole domain is treated simultaneously, has to be implemented. The variables and their derivatives in the equations are replaced with the appropriate finite difference representation. Using the expressions with error order (s^2), where s is the grid spacing, the derivatives have to be replaced for the interior of the domain with:

$$y'_i = \frac{y_{i+1} - y_{i-1}}{2s} + O(s^2)$$

$$y''_i = \frac{y_{i+1} - 2y_i + y_{i-1}}{s^2} + O(s^2)$$

$$y'''_i = \frac{y_{i+2} - 2y_{i+1} + 2y_{i-1} - y_{i-2}}{2s^3} + O(s^2)$$

The above expressions are directly derived from the expansion of the differential operator in terms of central differences. Near the inner boundary (actually one grid point away) expressions for the third derivative are needed in terms of forward differences:

$$y''' = \frac{5y_i - 18y_{i-1} + 24y_{i-2} - 14y_{i-3} + 3y_{i-4}}{2s^3} + O(s^2)$$

and near the outer boundary in backward differences:

$$y''' = \frac{-3y_{i+4} + 14y_{i+3} - 24y_{i+2} + 18y_{i+1} - 5y_i}{2s^3} + O(s^2)$$

This is done in order to avoid the introduction of virtual points in the finite difference expressions of the equations. Fortunately most of the boundary conditions are of Dirichlet type, and only one is of the Neumann type. The Dirichlet conditions do not constitute any problem at all at the boundary. The Neumann condition is the one which relates the radial vapor velocity term at the surface, g(0), to the gradient in the temperature term here, f(0). When a representation of the derivative is used in terms of forward differences up to order (s^2), the finite difference expression of the equation set is complete and ready to be treated numerically.

When N is the number of grid spacings, the set of simultaneous equations generates 3N + 3 linear algebraic equations, which can be represented by the matrix equation $\underline{A} \cdot \underline{Y} = \underline{B}$. Here is Y the variable factor consisting of:

$$Y = (h_1, h_2 \ldots\ldots h_{N+1}, g_1, g_2 \ldots\ldots g_{N+1}, f_1, f_2 \ldots\ldots\ldots f_{N+1})$$

A is the matrix of the coefficients which turns out to be a five

diagonal band matrix. Unfortunately the matrix A is not diagonally dominant so the convergence of a successive over-relaxation scheme cannot be guaranteed.

A direct solution method should be implemented. It turned out that the matrix was quite ill conditioned (the ratio of the largest to the smallest eigenvalue was about 1.000 on the average for the 63 by 63 matrix). A special routine* was used which applied Crout's method with row equilibration, row interchanges, and iterative improvement to the solution of the matrix equation. The program was run on an I.B.M. 7094 computer. The number of grid spacings, N, was 30, the largest value for which the matrix could be accomodated on the machine. The influence of the value of N was investigated and it was found that a change from N = 20 to N = 30 changed the results by less than 10%. The time required to obtain a solution was .5 minutes.

* Routine MX40 library L.R.L. # F4 EO MX40.

3.3. Results.

The results were obtained directly from the computer implemented numerical calculations. The program which was used, as well as the computer output, are presented in the appendix. The output is in the form of a table, representing the functions f, g and h as functions of x. One sample case is reworked for the components of the velocity vector correction as functions of r and is represented in table 2. The case of $Re_v=1$ and $\Delta=1$ is taken; others may be reworked similarly.

The result for the drag coefficient-convective Reynolds number product is for several values of Δ and vaporization Reynolds number is presented in table 1. The value, which is computed f from the numerical result, is stated. For comparison the value computed from the analytic expression derived above for the polynomial approximation of the third degree is mentioned between parenthesis. Clearly this approximate analytic expression for $C_d \cdot Re_c$ is only in fair agreement with the numerical results. However, for cases of practical interest (Δ smaller than 1 and Re_v up to 3) the approximate analytic expression can be used to provide an estimate of the friction coefficient.

For the case of the evaporation of a large droplet the use of the results is quite simple. The value of Δ^b can be computed from $p^*(\infty)$, since $p^*(\infty)$ gives the boiling point temperature of the droplet, the value of Re_v^b can be computed from $T^*(\infty)$, since $T^*(\infty)$ gives Θ^b. Then $C_d \cdot Re_c$ can be computed from the table or by use of the analytic expression, when the parameters are within the validity region. Clearly the friction coefficient is then known as a

function of Re_c, which expression is valid up to Re_c equals 0.1.

The force convective field around the evaporating droplet can be calculated by the superposition of the corrected radial flow field of the drop evaporating in a stagnant atmosphere and the results from the numerical or approximate analytic treatment of the forced flow problem. It should be noted that the influence of the correction is of order γ. The fields can now be directly computed by just adding the "convective solution" multiplied by γ to the radial flow field.

The resulting fields have the definite characteristics of the radial flow field near the droplet, although far from the droplet the radial flow field is negligible. As compared to the stokes flow situation near the drop, there is a distinct difference, not only because the radial flow is added, but also because the convective term is taken into account in the equation of motion. Thus, compared to the flow around a non-evaporating particle, the streamlines and stagnation point are displaced outward, decreasing the tangential velocity gradients near the droplet with attendant reduction frictional drag.

TABLE 1

	$\Delta=0.25$	$\Delta=1$	$\Delta=4$
$Re_v=0.$	12.00	12.00	12.00
	(12.00)	(12.00)	(12.00)
0.25	11.36	11.17	10.65
	(10.87)	(9.73)	(6.63)
0.5	10.80	10.44	9.71
	(10.12)	(8.34)	(4.44)
1	9.90	9.26	8.42
	(9.29)	(6.79)	(2.58)
2	8.68	7.67	6.89
	(8.85)	(5.60)	(1.45)
4	7.16	6.04	5.53
	(9.57)	(5.24)	(1.08)
8	4.91	4.58	4.53
	(12.17)	(5.81)	(1.25)

Table 1: Drag coefficient: $C_d \cdot Re_c$, numeric and ("analytic") values

TABLE 2

$Re_v = 1, \ \Delta = 1.$

"Convective" contribution to radial velocity: $u_I = \cos \ g(r)$

	r=1.	r=1.25	r=1.66	r=2.5	r=5	r=∞
$\theta = \pi$	+0.135	+0.080	-0.062	-0.292	-0.606	-1.
$\theta = \frac{5}{6}\pi$	+0.117	+0.069	-0.054	-0.252	-0.525	-0.866
$\theta = \frac{2}{3}\pi$	+0.068	+0.040	-0.031	-0.146	-0.303	-0.500
$\theta = \pi/2$	0.	0.	0.	0.	0.	0.
$\theta = \pi/3$	-0.068	-0.040	+0.031	+0.146	+0.303	+0.500
$\theta = \pi/6$	-0.117	-0.069	+0.054	+0.252	+0.525	+0.866
$\theta = 0$	-0.135	-0.080	+0.062	+0.292	+0.606	+1.

"Convective" contribution to tangential velocity: $v_I = - \sin h(r)$

	r=1.	r=1.25	r=1.66	r=2.5	r=5	r=∞
$\theta = \pi$	0.	0.	0.	0.	0.	0.
$\theta = \frac{5}{6}\pi$	0.	-0.086	-0.172	-0.254	-0.370	-0.500
$\theta = \frac{2}{3}\pi$	0.	-0.149	-0.297	-0.456	-0.640	-0.866
$\theta = \pi/2$	0.	-0.172	-0.343	-0.527	-0.739	-1.000
$\theta = \pi/3$	0.	-0.149	-0.297	-0.456	-0.640	-0.866
$\theta = \pi/6$	0.	-0.086	-0.172	-0.254	-0.370	-0.500
$\theta = 0$	0.	0.	0.	0.	0.	0.

4. CONCLUSIONS.

This study has been concerned with the evaporation of small droplets into its own vapor as well as with the evaporation in a convective environment of its own vapor. The two effects have been treated separately, and it was shown that the corrections derived for both effects are independent and can be superposed.

The correction forthe evaporation of a small droplet turned out only to be important if the droplet size diminishes to the order of the mean free path of the vapor molecules near the surface. An expression forthe total rate of change of the mass was obtained:

$$\dot{M}^* = k_0^*\left(1 - \frac{(K-1)C_w}{(R^*/\lambda^*(R))^2}\right)R^* \qquad (2.3\text{-}9)$$

This result is in agreement with otherwork[6], but the sign and the magnitude of the correction could be discussed on a quantitative basis here. The correction to evaporation rate due to the convective environment is negligible.

The correction for evaporation in convective environment was obtained in terms of the product of the drag coefficient and the Reynolds number, Re_c, describing the forced conventive flow.

It was found that the drag coefficient was lowered with respect to the case of Stokes flow and on approximate expression for $C_d \cdot Re_c$ was derived (3.1-4).

Stated in qualitative terms, the result is easily explained. Due to the high vapor flux at the surface, the forced convective flow is blown away from the surface of the droplet such that

the tangential velocity components cannot penetrate easily near the droplet. Consequently it might be expected, that, when vaporization takes place, the gradients of the tangential velocity in the radial direction are lowered near the sphere. This is what actually happens: $h'(0)$ is lowered as compared to the case of Stokes flow, therefore the skin friction is lowered, and the generation of the macroscopic impulse due to the unevenly distributed radial vapor velocity, is not big enough to offset this effect.

Future extensions of this work to include the effects of turbulent flow and diffusional mass transfer (environment of other than droplet vapor) are necessary. Investigation is also required for the droplet evaporating within a combustion shell in a convective field. Furthermore, the true implications of certain of the assumptions necessary in this treatment should be subjected to careful examination. The form of solution taken to eliminate Θ dependence possesses some undesirable characteristics which can be distinctly noted in the predicted temperature behavior near $r \longrightarrow \infty$. More rigorous approaches or experimental measurements may resolve this problem.

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APPENDIX.

This appendix contains the tabulated results as produced by the I.B.M. computer.

As an introduction the program, which was actually used, is presented.

The functions f, g and h are tabulated as functions of the independent variable x for various values of the parameters, Pr, Re_v and Δ.

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      DIMENSION A(93,93),B(93),W(50),W2(50),W3(50),W4(50),AX(50),
     1 WS2(50),W2S(50),HA(50),GA(50),FA(50),X(93),RAM(50)
      LOGICAL SINGUL
      INTEGER EX
      N=20
      P=0.75
  199 CONTINUE
      N=N+10
      D=.0625
  200 CONTINUE
      D=4.*D
      R=.125
      GO TO 300
  201 CONTINUE
  300 CONTINUE
      R=2.*R
      M1=N-1
      M2=3*N+3
      NN=N+1
      DO 11 I=1,M2
      DO 10 J=1,M2
      A(I,J)=0.
      B(I)=0.
   10 CONTINUE
   11 CONTINUE
      IF(R.GT.0.0001) GO TO 15
      R = 0.
   15 WRITE(3,16) R, P, D,N
   16 FORMAT (11H  REYNOLDS=,F10.7,10H  PRANDTL=,F10.7,8H  DELTA=,
     1 F10.7,3H N=,I3///)
      FN=N
      S=1./FN
      S2=S*S
      S3=S2*S
      DO 20 I=2,N
      FI=I-1
      RAM(I)=FI*S
      W(I)=1.-FI*S
      W2(I)=W(I)*W(I)
      W3(I)=W2(I)*W(I)
      W4(I)=W3(I)*W(I)
      AX(I)=R*P*D*EXP (R*P*FI*S)/(1.-D+D*EXP(R*P*FI*S))
      WS2(I)=W(I)*S2
      W2S(I)=W2(I)*S
      HA(I)=1.-.75*W(I)-.25*W3(I)
      GA(I)=1.-1.5*W(I)+0.5*W3(I)
      FA(I)=0.
   20 CONTINUE
      RAM(1)=0.
      HA(1)=0.
      GA(1)=0.
      FA(1)=0.
      RAM(N+1)=1.
      HA(N+1)=1.
      GA(N+1)=1.
```

```
      FA(N+1)=0.
      WRITE(3,401)(I,HA(I),GA(I),FA(I),AX(I),I=1,NN)
401   FORMAT(  (4H  I=,I3,4H HA=,F10.7,4H GA=,F10.7,4H FA=,F10.7,
     1 4H AX=,F10.6))
      A(1,1)=1.
      A(2,2)=R*S*(2.*W3(2)+2.*WS2(2))-2.5*W3(2)+6.*W2S(2)-2.*S3
      A(2,3)=R*S*(-W3(2)+W2S(2))+9.*W3(2)-3.*W2S(2)-WS2(2)
      A(2,4)=-12.*W3(2)
      A(2,5)=7.*W3(2)
      A(2,6)=-1.5*W3(2)
      A(2,N+2)=-0.5*R*S*W2S(2)-W2S(2)-WS2(2)
      A(2,N+3)=R*S*(S*W2S(2)*AX(2)-2.*WS2(2))+2.*W2S(2)+2.*S3
      A(2,N+4)=0.5*R*S*W2S(2)-W2S(2)+WS2(2)
      A(2,2*N+4)=R*S3*(2.0*W3(2)-W4(2)*AX(2))
      DO 31 I=3,M1
      NI=N+I
      N2I=2*N+I
      A(I,I-2)=-0.5*W3(I)
      A(I,I-1)=R*S*(-W3(I)-W2S(I))+W3(I)-3.*W2S(I)+WS2(I)
      A(I,I)=R*S*(2.*W3(I)+2.*WS2(I))+6.*W2S(I)-2.*S3
      A(I,I+1)=R*S*(-W3(I)+W2S(I))-W3(I)-3.*W2S(I)-WS2(I)
      A(I,I+2)=0.5*W3(I)
      A(I,NI  )=-0.5*R*S*W2S(I)-W2S(I)-WS2(I)
      A(I,NI+1  )=R*S*(S*W2S(I)*AX(I)-2.*WS2(I))+2.*W2S(I)+2.*S3
      A(I,NI+2  )=0.5*R*S*W2S(I)-W2S(I)+WS2(I)
      A(I,N2I+2   )=R*S3*(2.*W3(I)-W4(I)*AX(I))
31    CONTINUE
      A(N,N-4)=1.5*W3(N)
      A(N,N-3)=-7.*W3(N)
      A(N,N-2)=12.*W3(N)
      A(N,N-1)=R*S*(-W3(N)-W2S(N))-9.*W3(N)-3.*W2S(N)+WS2(N)
      A(N,N)=R*S*(2.*W3(N)+2.*WS2(N))+2.5*W3(N)+6.*W2S(N)-2.*S3
      A(N,N+1)=R*S*(-W3(N)+W2S(N))-3.*W2S(N)-WS2(N)
      A(N,2*N)=-0.5*R*S*W2S(N)-W2S(N)-WS2(N)
      A(N,2*N+1)=R*S*(S*W2S(N)*AX(N)-2.*WS2(N))+2.*W2S(N)+2.*S3
      A(N,2*N+2)=+0.5*R*S*W2S(N)-W2S(N)+WS2(N)
      A(N,3*N+2)=R*S3*(2.*W3(N)-W4(N)*AX(N))
      A(N+1,N+1)=1.
      B(N+1)=1.
      IF(R.LT.0.0001) GOTO 50
      A(N+2,N+2)=  S*R*P*D
      A(N+2,2*N+4)=-2.
      A(N+2,2*N+5)=0.5
      GO TO 51
50    A(N+2,N+2)=  S
51    CONTINUE
      DO 32 I=2,N
      NI=N+I
      N2I=2*N+I
      A(NI+1  ,I)=-2.*S
      A(NI+1  ,NI  )=-W(I)*0.5
      A(NI+1  ,NI+1 )=S*(2.-W(I)*AX(I))
      A(NI+1  ,NI+2 )=+W(I)*0.5
      A(NI+1  ,N2I+1   )=0.5*W3(I)
      A(NI+1  ,N2I+2   )=S*W3(I)*AX(I)
      A(NI+1  ,N2I+3   )=-0.5*W3(I)
```

```
 32   CONTINUE
      A(2*N+2,2*N+2)=1.
      B(2*N+2)=1.
      A(2*N+3,2*N+3)=1.
      DO 33 I=2,N
      NI=N+I
      N2I=2*N+I
      A(N2I+2  ,NI+1 )=-S2*R*P*AX(I)
      A(N2I+2  ,N2I+1  )=W2(I)+R*P*W2S(I)*0.5
      A(N2I+2  ,N2I+2)=-2.*W2(I)-2.*S2+R*P*S2*AX(I)*W2(I)
      A(N2I+2  ,N2I+3  )=W2(I)-0.5*R*P*W2S(I)
 33   CONTINUE
      A(3*N+3,3*N+3)=1.
      CALL MX40(A,B,X,M2,1,DET,EX,CNR,SINGUL)
      WRITE (3,101) DET,EX,CNR
101   FORMAT(6H  DET=,F10.5,5H  EX=,I5,6H  CNR=,E20.7)
      IF(N.EQ.20) GO TO 103
      IF(N.EQ.30) GO TO 105
      WRITE(3,102) (I,X(I),X(I+11),X(I+22),I=1,11)
102   FORMAT (11(4H  I=,I3,4H  H=,F10.7,4H  G=,F10.7,4H  F=,F10.7/))
      GO TO 107
103   WRITE(3,104) (I,X(I),X(I+21),X(I+42),I=1,21)
104   FORMAT (21(4H  I=,I3,4H  H=,F10.7,4H  G=,F10.7,4H  F=,F10.7/))
      GO TO 107
105   WRITE(3,371) R,P,D
371   FORMAT(1H1,/////,11H  REYNOLDS=,F10.7,10H  PRANDTL=,F10.7,
     1 8H  DELTA=,F10.7////)
      WRITE(3,372)
372   FORMAT(1H ,3X,11H VARIABLE X,4X,11H TAN.VEL. H,4X,
     1 11H RAD.VEL. G,4X,11H TEMP.FN. F//)
      WRITE(3,106) (RAM(I),X(I),X(I+31),X(I+62),I=1,31)
106   FORMAT(1H ,4X,F10.7,5X,F10.7,5X,F10.7,5X,F10.7)
      WRITE(3,373)
373   FORMAT(1H1)
107   CONTINUE
      IS= 1
      IF(SINGUL) IS= 2
      GO TO (151,152),IS
151   WRITE (3,161)
161   FORMAT(11H  A IS O.K.//)
      GO TO 163
152   WRITE (3,162)
162   FORMAT(15H  A IS SINGULAR//)
163   CONTINUE
      HP=(-.5*X(3)+2.*X(2) -1.5*X(1))/S
      HPP=(-X(4)+4.*X(3)-5.*X(2)+2.*X(1))/S2
      H4P=(11.*X(5)-56.*X(4)+114.*X(3)-104.*X(2)+35.*X(1))/(12.*S2)
      H5P=(-10.*X(6)+61.*X(5)-156.*X(4)+214.*X(3)-154.*X(2)+45.*X(1))/
     1 (12.*S2)
      GP=(-.5*X(NN+3)+2.*X(NN+2)-1.5*X(NN+1))/S
      GG=2.*R*X(NN+1)
      PG=-R*HP+HPP+GP/3.+8.*X(NN+1)/3.
      P4=-R*HP+H4P+GP/3.+8.*X(NN+1)/3.
      P5=-R*HP+H5P+GP/3.+8.*X(NN+1)/3.
      TR=-4.*(GP-X(NN+1))/3.
      TT=HP+X(NN+1)
```

```
      CDRE=(-8.*(GG+PG+TR)+16.*TT)/3.
      CDR5=(-8.*(GG+P5+TR)+16.*TT)/3.
      CDR4=(-8.*(GG+P4+TR)+16.*TT)/3.
      CDREA=(8.*(36.+12.*R-6.*R*P*D+3.*(R**2)))/(3.*(8.+5.*R+6.*R*P*D+
     1 P*D*(R**2)))
      WRITE(3,170)HP,HPP,GP,GG,PG,TR,TT,CDRE,P4,CDR4,P5,CDR5,CDREA
  170 FORMAT(5H  HP=,F10.6,5H HPP=,F10.6,4H GP=,F10.6,4H GG=,F10.6,
     1 4H PG=,F10.6,4H TR=,F10.6,4H TT=,F10.6,/7H  CDRE=,F20.6/,
     2 5H  P4=,F10.6,7H  CDR4=,F20.6/,5H  P5=,F10.6,7H  CDR5=,F20.6/,
     3 8H  CDREA=,F20.6/////)
      IF(R.LT..001) GO TO 201
      IF(R.LT.10.) GO TO 300
      IF(D.LT.10.) GO TO 200
      IF(N.LT.25) GO TO 199
      STOP
      END
```

REYNOLDS= 0.2500000 PRANDTL= 0.7500000 DELTA= 0.2500000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0625157	-0.
0.0333333	0.0435486	-0.0571311	-0.0000984
0.0666667	0.0860147	-0.0489932	-0.0001983
0.1000000	0.1274384	-0.0381737	-0.0002998
0.1333333	0.1678594	-0.0247444	-0.0004033
0.1666667	0.2073178	-0.0087772	-0.0005089
0.2000000	0.2458537	0.0096555	-0.0006170
0.2333333	0.2835073	0.0304814	-0.0007277
0.2666667	0.3203190	0.0536279	-0.0008414
0.3000000	0.3563291	0.0790221	-0.0009582
0.3333333	0.3915783	0.1065911	-0.0010785
0.3666667	0.4261070	0.1362616	-0.0012024
0.4000000	0.4599561	0.1679599	-0.0013303
0.4333333	0.4931664	0.2016125	-0.0014624
0.4666667	0.5257788	0.2371453	-0.0015989
0.5000000	0.5578344	0.2744842	-0.0017401
0.5333333	0.5893742	0.3135545	-0.0018862
0.5666667	0.6204396	0.3542817	-0.0020372
0.6000000	0.6510718	0.3965906	-0.0021934
0.6333333	0.6813123	0.4404060	-0.0023547
0.6666667	0.7112025	0.4856523	-0.0025210
0.7000000	0.7407841	0.5322539	-0.0026919
0.7333333	0.7700987	0.5801345	-0.0028667
0.7666667	0.7991879	0.6292178	-0.0030440
0.8000000	0.8280936	0.6794273	-0.0032212
0.8333333	0.8568575	0.7306861	-0.0033931
0.8666667	0.8855213	0.7829169	-0.0035494
0.9000000	0.9141264	0.8360425	-0.0036656
0.9333333	0.9427144	0.8899847	-0.0036726
0.9666667	0.9713257	0.9446657	-0.0032914
1.0000000	1.0000000	1.0000000	-0.

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REYNOLDS= 0.5000000 PRANDTL= 0.7500000 DELTA= 0.2500000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.1156937	-0.
0.0333333	0.0382960	-0.1075042	-0.0003666
0.0666667	0.0759560	-0.0969538	-0.0007432
0.1000000	0.1130105	-0.0840818	-0.0011308
0.1333333	0.1494899	-0.0689274	-0.0015307
0.1666667	0.1854252	-0.0515295	-0.0019437
0.2000000	0.2208471	-0.0319270	-0.0023713
0.2333333	0.2557868	-0.0101586	-0.0028144
0.2666667	0.2902753	0.0137368	-0.0032745
0.3000000	0.3243441	0.0397208	-0.0037527
0.3333333	0.3580247	0.0677548	-0.0042504
0.3666667	0.3913488	0.0978004	-0.0047691
0.4000000	0.4243483	0.1298191	-0.0053100
0.4333333	0.4570550	0.1637727	-0.0058747
0.4666667	0.4895013	0.1996226	-0.0064645
0.5000000	0.5217196	0.2373307	-0.0070809
0.5333333	0.5537422	0.2768586	-0.0077253
0.5666667	0.5856020	0.3181681	-0.0083990
0.6000000	0.6173316	0.3612207	-0.0091029
0.6333333	0.6489642	0.4059784	-0.0098380
0.6666667	0.6805328	0.4524027	-0.0106044
0.7000000	0.7120707	0.5004554	-0.0114016
0.7333333	0.7436111	0.5500985	-0.0122271
0.7666667	0.7751874	0.6012938	-0.0130760
0.8000000	0.8068330	0.6540034	-0.0139377
0.8333333	0.8385812	0.7081897	-0.0147911
0.8666667	0.8704650	0.7638155	-0.0155904
0.9000000	0.9025172	0.8208442	-0.0162274
0.9333333	0.9347700	0.8792401	-0.0163910
0.9666667	0.9672544	0.9389696	-0.0148142
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 1.0000000 PRANDTL= 0.7500000 DELTA= 0.2500000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.1945954	-0.
0.0333333	0.0290973	-0.1831872	-0.0012492
0.0666667	0.0582187	-0.1700293	-0.0025645
0.1000000	0.0873891	-0.1551112	-0.0039513
0.1333333	0.1166336	-0.1384205	-0.0054156
0.1666667	0.1459780	-0.1199432	-0.0069637
0.2000000	0.1754486	-0.0996639	-0.0086023
0.2333333	0.2050721	-0.0775654	-0.0103386
0.2666667	0.2348759	-0.0536286	-0.0121804
0.3000000	0.2648878	-0.0278331	-0.0141357
0.3333333	0.2951363	-0.0001563	-0.0162135
0.3666667	0.3256507	0.0294257	-0.0184229
0.4000000	0.3564607	0.0609390	-0.0207739
0.4333333	0.3875969	0.0944113	-0.0232769
0.4666667	0.4190904	0.1298722	-0.0259431
0.5000000	0.4509735	0.1673532	-0.0287839
0.5333333	0.4832787	0.2068876	-0.0318114
0.5666667	0.5160397	0.2485107	-0.0350379
0.6000000	0.5492910	0.2922599	-0.0384756
0.6333333	0.5830676	0.3381743	-0.0421362
0.6666667	0.6174057	0.3862956	-0.0460300
0.7000000	0.6523421	0.4366673	-0.0501639
0.7333333	0.6879143	0.4893355	-0.0545385
0.7666667	0.7241605	0.5443487	-0.0591423
0.8000000	0.7611197	0.6017583	-0.0639392
0.8333333	0.7988307	0.6616191	-0.0688415
0.8666667	0.8373329	0.7239899	-0.0736432
0.9000000	0.8766649	0.7889345	-0.0778258
0.9333333	0.9168640	0.8565243	-0.0798525
0.9666667	0.9579653	0.9268420	-0.0733517
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 2.0000000 PRANDTL= 0.7500000 DELTA= 0.2500000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.2566707	0.
0.0333333	0.0162389	-0.2455583	-0.0033856
0.0666667	0.0330815	-0.2335092	-0.0071257
0.1000000	0.0505605	-0.2204496	-0.0112564
0.1333333	0.0687114	-0.2062994	-0.0158173
0.1666667	0.0875723	-0.1909729	-0.0208521
0.2000000	0.1071843	-0.1743774	-0.0264089
0.2333333	0.1275915	-0.1564133	-0.0325405
0.2666667	0.1488418	-0.1369739	-0.0393050
0.3000000	0.1709868	-0.1159444	-0.0467665
0.3333333	0.1940824	-0.0932022	-0.0549952
0.3666667	0.2181891	-0.0686160	-0.0640687
0.4000000	0.2433723	-0.0420456	-0.0740719
0.4333333	0.2697031	-0.0133417	-0.0850985
0.4666667	0.2972585	0.0176550	-0.0972511
0.5000000	0.3261221	0.0511136	-0.1106420
0.5333333	0.3563845	0.0872139	-0.1253941
0.5666667	0.3881442	0.1261461	-0.1416408
0.6000000	0.4215080	0.1681121	-0.1595260
0.6333333	0.4565918	0.2133250	-0.1792028
0.6666667	0.4935212	0.2620100	-0.2008305
0.7000000	0.5324324	0.3144047	-0.2245680
0.7333333	0.5734728	0.3707598	-0.2505590
0.7666667	0.6168015	0.4313397	-0.2789032
0.8000000	0.6625898	0.4964237	-0.3095918
0.8333333	0.7110215	0.5663077	-0.3423609
0.8666667	0.7622926	0.6413073	-0.3763175
0.9000000	0.8166100	0.7217626	-0.4088410
0.9333333	0.8741886	0.8080489	-0.4315222
0.9666667	0.9352468	0.9006008	-0.4080711
1.0000000	1.0000000	1.0000000	-0.

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REYNOLDS= 4.0000000 PRANDTL= 0.7500000 DELTA= 0.2500000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	-0.	-0.1808385	-0.
0.0333333	0.0069150	-0.1779573	-0.0050561
0.0666667	0.0143039	-0.1751156	-0.0111824
0.1000000	0.0221892	-0.1722321	-0.0185618
0.1333333	0.0305995	-0.1692095	-0.0274055
0.1666667	0.0395680	-0.1659327	-0.0379573
0.2000000	0.0491358	-0.1622661	-0.0504979
0.2333333	0.0593515	-0.1580515	-0.0653508
0.2666667	0.0702744	-0.1531055	-0.0828879
0.3000000	0.0819758	-0.1472167	-0.1035362
0.3333333	0.0945419	-0.1401432	-0.1277860
0.3666667	0.1080759	-0.1316099	-0.1561994
0.4000000	0.1227026	-0.1213056	-0.1894201
0.4333333	0.1385709	-0.1088809	-0.2281843
0.4666667	0.1558595	-0.0939453	-0.2733334
0.5000000	0.1747814	-0.0760657	-0.3258274
0.5333333	0.1955902	-0.0547635	-0.3867597
0.5666667	0.2185868	-0.0295139	-0.4573733
0.6000000	0.2441275	0.0002563	-0.5390762
0.6333333	0.2726326	0.0351694	-0.6334560
0.6666667	0.3045963	0.0758985	-0.7422885
0.7000000	0.3405980	0.1231683	-0.8675328
0.7333333	0.3813143	0.1777588	-1.0112950
0.7666667	0.4275322	0.2405076	-1.1757184
0.8000000	0.4801626	0.3123190	-1.3627017
0.8333333	0.5402542	0.3941752	-1.5731757
0.8666667	0.6090055	0.4871627	-1.8051387
0.9000000	0.6877739	0.5925109	-2.0476078
0.9333333	0.7780739	0.7116825	-2.2575879
0.9666667	0.8815619	0.8465464	-2.2322696
1.0000000	1.0000000	1.0000000	0.

REYNOLDS= 8.0000000 PRANDTL= 0.7500000 DELTA= 0.2500000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0383998	0.0000000
0.0333333	0.0045954	-0.0400277	-0.0024557
0.0666667	0.0093743	-0.0422026	-0.0059829
0.1000000	0.0143329	-0.0449625	-0.0109377
0.1333333	0.0194597	-0.0484269	-0.0177754
0.1666667	0.0247401	-0.0526147	-0.0270750
0.2000000	0.0301595	-0.0576119	-0.0395661
0.2333333	0.0356972	-0.0633879	-0.0561636
0.2666667	0.0413384	-0.0699575	-0.0780056
0.3000000	0.0470642	-0.0771998	-0.1065011
0.3333333	0.0528701	-0.0850114	-0.1433823
0.3666667	0.0587551	-0.0931319	-0.1907698
0.4000000	0.0647459	-0.1012867	-0.2512436
0.4333333	0.0708889	-0.1090220	-0.3279312
0.4666667	0.0772807	-0.1158391	-0.4246031
0.5000000	0.0840660	-0.1210409	-0.5457909
0.5333333	0.0914765	-0.1238605	-0.6969169
0.5666667	0.0998392	-0.1233206	-0.8844523
0.6000000	0.1096284	-0.1183604	-1.1160924
0.6333333	0.1214883	-0.1077066	-1.4009727
0.6666667	0.1363050	-0.0899998	-1.7499060
0.7000000	0.1552516	-0.0636641	-2.1756690
0.7333333	0.1798899	-0.0270253	-2.6932870
0.7666667	0.2122486	0.0218597	-3.3202896
0.8000000	0.2549709	0.0851325	-4.0766351
0.8333333	0.3114416	0.1654412	-4.9835705
0.8666667	0.3860093	0.2660231	-6.0584663
0.9000000	0.4841848	0.3914009	-7.2945697
0.9333333	0.6129857	0.5478720	-8.5703179
0.9666667	0.7812143	0.7454372	-9.0955217
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS=16.0000000 PRANDTL= 0.7500000 DELTA= 0.2500000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	-0.	0.1710131	-0.0000000
0.0333333	-0.0609480	-0.1612535	0.0145448
0.0666667	-0.0300235	0.1607975	0.0239766
0.1000000	-0.0325031	-0.1083190	0.0518816
0.1333333	-0.0307601	0.1497022	0.0744160
0.1666667	-0.0167361	-0.0351391	0.1240489
0.2000000	-0.0195468	0.1528981	0.1741513
0.2333333	-0.0016444	0.0493433	0.2602405
0.2666667	-0.0007960	0.1836236	0.3607858
0.3000000	0.0183775	0.1427262	0.5100212
0.3333333	0.0256465	0.2451045	0.6963314
0.3666667	0.0470746	0.2467571	0.9526884
0.4000000	0.0619071	0.3322138	1.2787184
0.4333333	0.0875770	0.3586303	1.7081647
0.4666667	0.1106353	0.4311423	2.2507714
0.5000000	0.1421572	0.4638262	2.9412673
0.5333333	0.1732870	0.5156074	3.7941025
0.5666667	0.2105616	0.5317581	4.8378611
0.6000000	0.2474014	0.5447726	6.0751985
0.6333333	0.2868174	0.5181405	7.5037963
0.6666667	0.3227761	0.4716990	9.0728527
0.7000000	0.3554247	0.3837663	10.6887170
0.7333333	0.3786475	0.2745347	12.1583487
0.7666667	0.3914469	0.1410714	13.1789408
0.8000000	0.3898921	0.0168544	13.2652986
0.8333333	0.3777422	-0.0784061	11.7477704
0.8666667	0.3622560	-0.0956562	7.7325736
0.9000000	0.3668616	-0.0105707	0.2955857
0.9333333	0.4289846	0.2089575	11.0483030
0.9666667	0.6141450	0.5308010	23.3570540
1.0000000	1.0000000	1.0000000	0.

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REYNOLDS= 0.2500000 PRANDTL= 0.7500000 DELTA= 1.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0566653	-0.
0.0333333	0.0429620	-0.0521650	-0.0003568
0.0666667	0.0848344	-0.0448640	-0.0007188
0.1000000	0.1256590	-0.0348257	-0.0010870
0.1333333	0.1654781	-0.0221148	-0.0014621
0.1666667	0.2043348	-0.0067973	-0.0018450
0.2000000	0.2422724	0.0110596	-0.0022365
0.2333333	0.2793349	0.0313871	-0.0026375
0.2666667	0.3155669	0.0541152	-0.0030488
0.3000000	0.3510135	0.0791723	-0.0034712
0.3333333	0.3857205	0.1064855	-0.0039057
0.3666667	0.4197342	0.1359803	-0.0043529
0.4000000	0.4531013	0.1675806	-0.0048137
0.4333333	0.4858694	0.2012089	-0.0052887
0.4666667	0.5180864	0.2367860	-0.0057786
0.5000000	0.5498011	0.2742312	-0.0062841
0.5333333	0.5810625	0.3134621	-0.0068055
0.5666667	0.6119205	0.3543946	-0.0073432
0.6000000	0.6424255	0.3969430	-0.0078972
0.6333333	0.6726283	0.4410198	-0.0084672
0.6666667	0.7025805	0.4865359	-0.0090523
0.7000000	0.7323342	0.5334004	-0.0096507
0.7333333	0.7619420	0.5815207	-0.0102593
0.7666667	0.7914570	0.6308023	-0.0108725
0.8000000	0.8209327	0.6811493	-0.0114802
0.8333333	0.8504233	0.7324638	-0.0120639
0.8666667	0.8799830	0.7846461	-0.0125856
0.9000000	0.9096664	0.8375956	-0.0129587
0.9333333	0.9395281	0.8912086	-0.0129403
0.9666667	0.9696216	0.9453817	-0.0115543
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 0.5000000 PRANDTL= 0.7500000 DELTA= 1.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0954527	-0.
0.0333333	0.0375874	-0.0901814	-0.0012097
0.0666667	0.0744716	-0.0823475	-0.0024525
0.1000000	0.1106894	-0.0719809	-0.0037317
0.1333333	0.1462787	-0.0591137	-0.0050507
0.1666667	0.1812783	-0.0437790	-0.0064129
0.2000000	0.2157280	-0.0260120	-0.0078218
0.2333333	0.2496686	-0.0058496	-0.0092809
0.2666667	0.2831421	0.0166692	-0.0107937
0.3000000	0.3161913	0.0415038	-0.0123639
0.3333333	0.3488604	0.0686111	-0.0139951
0.3666667	0.3811944	0.0979459	-0.0156906
0.4000000	0.4132396	0.1294608	-0.0174542
0.4333333	0.4450435	0.1631061	-0.0192890
0.4666667	0.4766546	0.1988293	-0.0211983
0.5000000	0.5081224	0.2365756	-0.0231851
0.5333333	0.5394979	0.2762877	-0.0252518
0.5666667	0.5708330	0.3179052	-0.0274004
0.6000000	0.6021809	0.3613654	-0.0296318
0.6333333	0.6335956	0.4066025	-0.0319456
0.6666667	0.6651327	0.4535479	-0.0343393
0.7000000	0.6968483	0.5021303	-0.0368071
0.7333333	0.7288000	0.5522755	-0.0393373
0.7666667	0.7610459	0.6039066	-0.0419092
0.8000000	0.7936451	0.6569439	-0.0444840
0.8333333	0.8266573	0.7113056	-0.0469888
0.8666667	0.8601425	0.7669074	-0.0492743
0.9000000	0.8941608	0.8236641	-0.0509959
0.9333333	0.9287718	0.8814883	-0.0511842
0.9666667	0.9640329	0.9402964	-0.0459351
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 1.0000000 PRANDTL= 0.7500000 DELTA= 1.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.1349516	-0.
0.0333333	0.0290425	-0.1315633	-0.0034653
0.0666667	0.0578539	-0.1258625	-0.0071136
0.1000000	0.0864739	-0.1178297	-0.0109595
0.1333333	0.1149444	-0.1074459	-0.0150184
0.1666667	0.1433094	-0.0946933	-0.0193061
0.2000000	0.1716152	-0.0795552	-0.0238390
0.2333333	0.1999104	-0.0620163	-0.0286340
0.2666667	0.2282461	-0.0420632	-0.0337088
0.3000000	0.2566758	-0.0196842	-0.0390812
0.3333333	0.2852558	0.0051301	-0.0447698
0.3666667	0.3140450	0.0323869	-0.0507934
0.4000000	0.3431052	0.0620902	-0.0571713
0.4333333	0.3725009	0.0942417	-0.0639227
0.4666667	0.4022997	0.1288394	-0.0710667
0.5000000	0.4325720	0.1658783	-0.0786222
0.5333333	0.4633914	0.2053494	-0.0866070
0.5666667	0.4948344	0.2472403	-0.0950372
0.6000000	0.5269807	0.2915343	-0.1039264
0.6333333	0.5599127	0.3382111	-0.1132832
0.6666667	0.5937162	0.3872461	-0.1231093
0.7000000	0.6284794	0.4386109	-0.1333936
0.7333333	0.6642934	0.4922733	-0.1441049
0.7666667	0.7012514	0.5481981	-0.1551750
0.8000000	0.7394487	0.6063471	-0.1664682
0.8333333	0.7789818	0.6666813	-0.1777131
0.8666667	0.8199477	0.7291609	-0.1883371
0.9000000	0.8624424	0.7937508	-0.1969919
0.9333333	0.9065592	0.8604208	-0.1998339
0.9666667	0.9523852	0.9291629	-0.1812748
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 2.0000000 PRANDTL= 0.7500000 DELTA= 1.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.1343016	0.
0.0333333	0.0184714	-0.1379535	-0.0070856
0.0666667	0.0369911	-0.1397936	-0.0149122
0.1000000	0.0556079	-0.1397233	-0.0235524
0.1333333	0.0743766	-0.1376394	-0.0330839
0.1666667	0.0933574	-0.1334346	-0.0435897
0.2000000	0.1126171	-0.1269983	-0.0551581
0.2333333	0.1322291	-0.1182166	-0.0678837
0.2666667	0.1522748	-0.1069728	-0.0818666
0.3000000	0.1728431	-0.0931484	-0.0972138
0.3333333	0.1940317	-0.0766233	-0.1140383
0.3666667	0.2159477	-0.0572764	-0.1324601
0.4000000	0.2387080	-0.0349868	-0.1526058
0.4333333	0.2624401	-0.0096337	-0.1746086
0.4666667	0.2872826	0.0189021	-0.1986084
0.5000000	0.3133863	0.0507383	-0.2247506
0.5333333	0.3409143	0.0859898	-0.2531859
0.5666667	0.3700430	0.1247688	-0.2840674
0.6000000	0.4009625	0.1671839	-0.3175485
0.6333333	0.4338774	0.2133407	-0.3537766
0.6666667	0.4690066	0.2633410	-0.3928841
0.7000000	0.5065843	0.3172848	-0.4349718
0.7333333	0.5468596	0.3752699	-0.4800785
0.7666667	0.5900958	0.4373964	-0.5281232
0.8000000	0.6365704	0.5037675	-0.5787867
0.8333333	0.6865730	0.5744984	-0.6312508
0.8666667	0.7404030	0.6497204	-0.6835511
0.9000000	0.7983647	0.7296002	-0.7307059
0.9333333	0.8607615	0.8143540	-0.7578709
0.9666667	0.9278829	0.9043092	-0.7033179
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 4.0000000 PRANDTL= 0.7500000 DELTA= 1.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0691357	0.
0.0333333	0.0101910	-0.0783274	-0.0077306
0.0666667	0.0203679	-0.0871216	-0.0170953
0.1000000	0.0305501	-0.0953920	-0.0283644
0.1333333	0.0407665	-0.1029923	-0.0418428
0.1666667	0.0510527	-0.1097524	-0.0578732
0.2000000	0.0614563	-0.1154799	-0.0768403
0.2333333	0.0720365	-0.1199568	-0.0991753
0.2666667	0.0828680	-0.1229416	-0.1253604
0.3000000	0.0940422	-0.1241655	-0.1559340
0.3333333	0.1056719	-0.1233362	-0.1914961
0.3666667	0.1178932	-0.1201341	-0.2327149
0.4000000	0.1308701	-0.1142165	-0.2803327
0.4333333	0.1447987	-0.1052148	-0.3351731
0.4666667	0.1599120	-0.0927393	-0.3981488
0.5000000	0.1764850	-0.0763767	-0.4702687
0.5333333	0.1948413	-0.0556956	-0.5526459
0.5666667	0.2153586	-0.0302435	-0.6465053
0.6000000	0.2384771	0.0004480	-0.7531882
0.6333333	0.2647061	0.0368672	-0.8741546
0.6666667	0.2946337	0.0795189	-1.0109756
0.7000000	0.3289342	0.1289328	-1.1653071
0.7333333	0.3683793	0.1856641	-1.3388253
0.7666667	0.4138457	0.2503120	-1.5330728
0.8000000	0.4663265	0.3235305	-1.7491020
0.8333333	0.5269375	0.4060669	-1.9866067
0.8666667	0.5969261	0.4987961	-2.2416153
0.9000000	0.6776700	0.6028086	-2.4994806
0.9333333	0.7706755	0.7195050	-2.7083176
0.9666667	0.8775509	0.8508692	-2.6319687
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 8.0000000 PRANDTL= 0.7500000 DELTA= 1.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0128758	0.0000000
0.0333333	0.0054665	-0.0175670	-0.0032897
0.0666667	0.0109777	-0.0229795	-0.0080085
0.1000000	0.0165304	-0.0289829	-0.0146150
0.1333333	0.0221024	-0.0357845	-0.0236750
0.1666667	0.0276714	-0.0432588	-0.0358913
0.2000000	0.0332226	-0.0515252	-0.0521234
0.2333333	0.0387280	-0.0604224	-0.0734252
0.2666667	0.0441802	-0.0699601	-0.1010747
0.3000000	0.0495593	-0.0798973	-0.1366222
0.3333333	0.0548755	-0.0901029	-0.1819324
0.3666667	0.0601360	-0.1002101	-0.2392466
0.4000000	0.0653910	-0.1099111	-0.3112406
0.4333333	0.0707064	-0.1186686	-0.4011042
0.4666667	0.0762122	-0.1259651	-0.5126197
0.5000000	0.0820845	-0.1310581	-0.6502651
0.5333333	0.0885986	-0.1331988	-0.8193193
0.5666667	0.0961233	-0.1314217	-1.0259997
0.6000000	0.1051834	-0.1247456	-1.2776059
0.6333333	0.1164693	-0.1119838	-1.5827098
0.6666667	0.1309163	-0.0919330	-1.9513586
0.7000000	0.1497355	-0.0631823	-2.3953389
0.7333333	0.1745195	-0.0242808	-2.9284389
0.7666667	0.2073041	0.0265058	-3.5667101
0.8000000	0.2507187	0.0910888	-4.3284169
0.8333333	0.3080941	0.1719646	-5.2329943
0.8666667	0.3836902	0.2722669	-6.2960231
0.9000000	0.4828779	0.3965998	-7.5092376
0.9333333	0.6125118	0.5514436	-8.7497778
0.9666667	0.7812080	0.7472491	-9.2236669
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS=16.0000000 PRANDTL= 0.7500000 DELTA= 1.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	-0.	0.0167844	0.0000000
0.0333333	-0.0022382	-0.0119048	0.0064109
0.0666667	0.0021061	0.0152167	0.0122162
0.1000000	0.0044784	0.0034739	0.0220134
0.1333333	0.0074947	0.0209091	0.0332399
0.1666667	0.0113762	0.0185255	0.0491220
0.2000000	0.0149110	0.0318877	0.0686526
0.2333333	0.0197277	0.0350857	0.0944808
0.2666667	0.0243803	0.0469844	0.1267120
0.3000000	0.0302554	0.0535024	0.1678444
0.3333333	0.0363262	0.0646685	0.2187633
0.3666667	0.0435333	0.0724585	0.2818571
0.4000000	0.0512226	0.0820334	0.3582071
0.4333333	0.0599630	0.0884006	0.4494289
0.4666667	0.0693024	0.0939055	0.5553227
0.5000000	0.0795029	0.0950417	0.6745493
0.5333333	0.0901472	0.0925565	0.8020076
0.5666667	0.1012068	0.0838722	0.9280242
0.6000000	0.1121769	0.0692358	1.0345038
0.6333333	0.1227753	0.0473665	1.0918272
0.6666667	0.1324428	0.0195334	1.0524679
0.7000000	0.1409201	-0.0128868	0.8444073
0.7333333	0.1481156	-0.0454595	0.3608596
0.7666667	0.1548564	-0.0721815	-0.5503926
0.8000000	0.1633327	-0.0834996	-2.1004301
0.8333333	0.1784881	-0.0679473	-4.5687614
0.8666667	0.2095252	-0.0114915	-8.3036028
0.9000000	0.2726560	0.1001390	13.6718611
0.9333333	0.3943737	0.2832050	20.7848344
0.9666667	0.6163363	0.5612898	27.5436265
1.0000000	1.0000000	1.0000000	0.

REYNOLDS= 0.2500000 PRANDTL= 0.7500000 DELTA= 4.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0416905	-0.
0.0333333	0.0413825	-0.0395153	-0.0010500
0.0666667	0.0816575	-0.0344003	-0.0021154
0.1000000	0.1208729	-0.0263766	-0.0031985
0.1333333	0.1590788	-0.0154829	-0.0043016
0.1666667	0.1963271	-0.0017650	-0.0054268
0.2000000	0.2326717	0.0147241	-0.0065760
0.2333333	0.2681684	0.0339245	-0.0077512
0.2666667	0.3028750	0.0557695	-0.0089540
0.3000000	0.3368509	0.0801859	-0.0101861
0.3333333	0.3701571	0.1070941	-0.0114489
0.3666667	0.4028564	0.1364083	-0.0127435
0.4000000	0.4350129	0.1680367	-0.0140709
0.4333333	0.4666925	0.2018817	-0.0154319
0.4666667	0.4979620	0.2378402	-0.0168267
0.5000000	0.5288897	0.2758037	-0.0182553
0.5333333	0.5595450	0.3156587	-0.0197170
0.5666667	0.5899982	0.3572867	-0.0212106
0.6000000	0.6203204	0.4005651	-0.0227338
0.6333333	0.6505836	0.4453668	-0.0242832
0.6666667	0.6808601	0.4915612	-0.0258533
0.7000000	0.7112226	0.5390144	-0.0274364
0.7333333	0.7417436	0.5875897	-0.0290200
0.7666667	0.7724956	0.6371484	-0.0305852
0.8000000	0.8035502	0.6875505	-0.0321005
0.8333333	0.8349780	0.7386556	-0.0335105
0.8666667	0.8668478	0.7903242	-0.0347083
0.9000000	0.8992259	0.8424194	-0.0354563
0.9333333	0.9321744	0.8948094	-0.0351013
0.9666667	0.9657499	0.9473712	-0.0310473
1.0000000	1.0000000	1.0000000	-0.

FORM 1013 14 x 11 - 3 LINES PER INCH Continuous Interfold © Moore Business Forms

REYNOLDS= 0.5000000 PRANDTL= 0.7500000 DELTA= 4.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0576808	-0.
0.0333333	0.0360847	-0.0581227	-0.0029239
0.0666667	0.0713380	-0.0555657	-0.0059275
0.1000000	0.1058116	-0.0499949	-0.0090180
0.1333333	0.1395608	-0.0414102	-0.0122021
0.1666667	0.1726442	-0.0298245	-0.0154862
0.2000000	0.2051238	-0.0152636	-0.0188760
0.2333333	0.2370644	0.0022350	-0.0223770
0.2666667	0.2685336	0.0226222	-0.0259940
0.3000000	0.2996018	0.0458384	-0.0297313
0.3333333	0.3303419	0.0718138	-0.0335926
0.3666667	0.3608289	0.1004690	-0.0375806
0.4000000	0.3911402	0.1317155	-0.0416976
0.4333333	0.4213548	0.1654563	-0.0459445
0.4666667	0.4515536	0.2015864	-0.0503215
0.5000000	0.4818188	0.2399934	-0.0548268
0.5333333	0.5122340	0.2805581	-0.0594575
0.5666667	0.5428835	0.3231554	-0.0642078
0.6000000	0.5738522	0.3676544	-0.0690693
0.6333333	0.6052255	0.4139199	-0.0740296
0.6666667	0.6370885	0.4618130	-0.0790702
0.7000000	0.6695256	0.5111920	-0.0841643
0.7333333	0.7026203	0.5619140	-0.0892719
0.7666667	0.7364541	0.6138360	-0.0943313
0.8000000	0.7711061	0.6668168	-0.0992419
0.8333333	0.8066521	0.7207190	-0.1038290
0.8666667	0.8431628	0.7754121	-0.1077563
0.9000000	0.8807031	0.8307759	-0.1102800
0.9333333	0.9193290	0.8867062	-0.1093575
0.9666667	0.9590849	0.9431236	-0.0968765
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 1.0000000 PRANDTL= 0.7500000 DELTA= 4.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0637998	-0.
0.0333333	0.0286708	-0.0708114	-0.0065524
0.0666667	0.0567870	-0.0746915	-0.0134496
0.1000000	0.0844133	-0.0753542	-0.0207159
0.1333333	0.1116202	-0.0727389	-0.0283741
0.1666667	0.1384844	-0.0668075	-0.0364460
0.2000000	0.1650876	-0.0575413	-0.0449523
0.2333333	0.1915168	-0.0449394	-0.0539122
0.2666667	0.2178634	-0.0290174	-0.0633439
0.3000000	0.2442238	-0.0098051	-0.0732641
0.3333333	0.2706983	0.0126533	-0.0836878
0.3666667	0.2973913	0.0383014	-0.0946285
0.4000000	0.3244107	0.0670704	-0.1060974
0.4333333	0.3518680	0.0988810	-0.1181034
0.4666667	0.3798776	0.1336435	-0.1306525
0.5000000	0.4085568	0.1712592	-0.1437467
0.5333333	0.4380248	0.2116210	-0.1573839
0.5666667	0.4684031	0.2546150	-0.1715554
0.6000000	0.4998142	0.3001211	-0.1862448
0.6333333	0.5323816	0.3480153	-0.2014244
0.6666667	0.5662285	0.3981703	-0.2170504
0.7000000	0.6014778	0.4504587	-0.2330552
0.7333333	0.6382502	0.5047542	-0.2493333
0.7666667	0.6766640	0.5609353	-0.2657163
0.8000000	0.7168331	0.6188882	-0.2819238
0.8333333	0.7588654	0.6785121	-0.2974561
0.8666667	0.8028607	0.7397233	-0.3113363
0.9000000	0.8489079	0.8024651	-0.3213725
0.9333333	0.8970812	0.8667158	-0.3214888
0.9666667	0.9474345	0.9325150	-0.2873894
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 2.0000000 PRANDTL= 0.7500000 DELTA= 4.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0497376	0.
0.0333333	0.0196804	-0.0651764	-0.0104945
0.0666667	0.0389753	-0.0779895	-0.0220829
0.1000000	0.0579558	-0.0879754	-0.0348615
0.1333333	0.0767029	-0.0949664	-0.0489270
0.1666667	0.0953083	-0.0988182	-0.0643772
0.2000000	0.1138736	-0.0994062	-0.0813114
0.2333333	0.1325107	-0.0966207	-0.0998306
0.2666667	0.1513417	-0.0903672	-0.1200377
0.3000000	0.1704994	-0.0805627	-0.1420373
0.3333333	0.1901272	-0.0671372	-0.1659358
0.3666667	0.2103793	-0.0500316	-0.1918407
0.4000000	0.2314215	-0.0291988	-0.2198609
0.4333333	0.2534306	-0.0046018	-0.2501053
0.4666667	0.2765953	0.0237848	-0.2826824
0.5000000	0.3011158	0.0559770	-0.3176985
0.5333333	0.3272045	0.0919806	-0.3552561
0.5666667	0.3550853	0.1317937	-0.3954503
0.6000000	0.3849938	0.1754064	-0.4383646
0.6333333	0.4171772	0.2228047	-0.4840628
0.6666667	0.4518935	0.2739712	-0.5325770
0.7000000	0.4894108	0.3288910	-0.5838863
0.7333333	0.5300067	0.3875536	-0.6378791
0.7666667	0.5739661	0.4499624	-0.6942821
0.8000000	0.6215799	0.5161385	-0.7525165
0.8333333	0.6731414	0.5861367	-0.8113823
0.8666667	0.7289435	0.6600528	-0.8682792
0.9000000	0.7892714	0.7380535	-0.9169554
0.9333333	0.8543976	0.8203904	-0.9392819
0.9666667	0.9245667	0.9074847	-0.8607799
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 4.0000000 PRANDTL= 0.7500000 DELTA= 4.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0215815	0.
0.0333333	0.0114089	-0.0373458	-0.0096490
0.0666667	0.0225398	-0.0524196	-0.0213309
0.1000000	0.0334190	-0.0665685	-0.0353592
0.1333333	0.0440843	-0.0795792	-0.0520754
0.1666667	0.0545849	-0.0912300	-0.0718538
0.2000000	0.0649842	-0.1012955	-0.0951054
0.2333333	0.0753600	-0.1095328	-0.1222824
0.2666667	0.0858080	-0.1156888	-0.1538813
0.3000000	0.0964431	-0.1194901	-0.1904481
0.3333333	0.1074035	-0.1206523	-0.2325821
0.3666667	0.1188527	-0.1188714	-0.2809406
0.4000000	0.1309841	-0.1138332	-0.3362441
0.4333333	0.1440239	-0.1052063	-0.3992813
0.4666667	0.1582371	-0.0926514	-0.4709147
0.5000000	0.1739304	-0.0758148	-0.5520860
0.5333333	0.1914597	-0.0543376	-0.6438217
0.5666667	0.2112337	-0.0278476	-0.7472378
0.6000000	0.2337225	0.0040317	-0.8635428
0.6333333	0.2594621	0.0416927	-0.9940363
0.6666667	0.2890639	0.0855370	-1.1400986
0.7000000	0.3232202	0.1359937	-1.3031622
0.7333333	0.3627145	0.1935184	-1.4846418
0.7666667	0.4084269	0.2586239	-1.6857750
0.8000000	0.4613449	0.3318904	-1.9072528
0.8333333	0.5225674	0.4140211	-2.1483214
0.8666667	0.5933142	0.5058725	-2.4043948
0.9000000	0.6749226	0.6085662	-2.6597890
0.9333333	0.7688515	0.7235657	-2.8601571
0.9666667	0.8766549	0.8529858	-2.7598158
1.0000000	1.0000000	1.0000000	-0.

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REYNOLDS= 8.0000000 PRANDTL= 0.7500000 DELTA= 4.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	-0.	-0.0038760	-0.
0.0333333	0.0057413	-0.0101190	-0.0039404
0.0666667	0.0114447	-0.0172930	-0.0095602
0.1000000	0.0171227	-0.0249287	-0.0173757
0.1333333	0.0227481	-0.0333729	-0.0279932
0.1666667	0.0282995	-0.0423626	-0.0421640
0.2000000	0.0337678	-0.0520694	-0.0607902
0.2333333	0.0391244	-0.0622548	-0.0849709
0.2666667	0.0443712	-0.0729452	-0.1160241
0.3000000	0.0494901	-0.0838471	-0.1555383
0.3333333	0.0545026	-0.0948309	-0.2054075
0.3666667	0.0594218	-0.1054915	-0.2678937
0.4000000	0.0643117	-0.1155196	-0.3456776
0.4333333	0.0692483	-0.1243537	-0.4419354
0.4666667	0.0743784	-0.1314818	-0.5604088
0.5000000	0.0798923	-0.1361558	-0.7055026
0.5333333	0.0860846	-0.1376498	-0.8823799
0.5666667	0.0933412	-0.1350182	-1.0970917
0.6000000	0.1022069	-0.1273283	-1.3567091
0.6333333	0.1133886	-0.1134436	-1.6695053
0.6666667	0.1278380	-0.0922382	-2.0451486
0.7000000	0.1467758	-0.0623783	-2.4949635
0.7333333	0.1717997	-0.0225095	-3.0321921
0.7666667	0.2049387	0.0290197	-3.6722720
0.8000000	0.2488049	0.0940371	-4.4328133
0.8333333	0.3066941	0.1749982	-5.3326221
0.8666667	0.3828174	0.2750243	-6.3867708
0.9000000	0.4824771	0.3987899	-7.5867727
0.9333333	0.6124553	0.5528837	-8.8099587
0.9666667	0.7812936	0.7479595	-9.2625293
1.0000000	1.0000000	1.0000000	0.

FORM 1013 14½ X 11 - 3 LINES PER INCH Continuous Interfold © Moore Business Forms, Inc.

REYNOLDS=16.0000000 PRANDTL= 0.7500000 DELTA= 4.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	-0.	0.0033411	-0.
0.0333333	0.0017025	0.0009435	0.0058432
0.0666667	0.0044742	0.0080294	0.0126814
0.1000000	0.0072166	0.0108115	0.0219341
0.1333333	0.0103225	0.0173098	0.0336700
0.1666667	0.0138188	0.0224634	0.0488942
0.2000000	0.0176519	0.0297045	0.0682430
0.2333333	0.0220189	0.0366111	0.0928776
0.2666667	0.0268440	0.0447844	0.1238580
0.3000000	0.0323066	0.0528329	0.1625962
0.3333333	0.0383685	0.0613798	0.2104413
0.3666667	0.0451578	0.0693789	0.2688553
0.4000000	0.0526485	0.0767843	0.3389822
0.4333333	0.0608966	0.0825410	0.4214937
0.4666667	0.0698349	0.0860760	0.5158811
0.5000000	0.0794076	0.0862014	0.6197276
0.5333333	0.0894376	0.0820313	0.7272963
0.5666667	0.0997062	0.0724500	0.8277143
0.6000000	0.1098766	0.0568120	0.9021345
0.6333333	0.1195708	0.0348337	0.9199537
0.6666667	0.1283810	0.0072878	0.8334681
0.7000000	0.1360362	-0.0237789	0.5709621
0.7333333	0.1426161	-0.0543393	0.0277630
0.7666667	0.1490062	-0.0781127	-0.9443510
0.8000000	0.1575804	-0.0861958	-2.5487849
0.8333333	0.1733340	-0.0673622	-5.0536527
0.8666667	0.2055445	-0.0086064	-8.7905788
0.9000000	0.2702379	0.1039588	14.1081641
0.9333333	0.3935957	0.2860143	21.1025918
0.9666667	0.6165559	0.5625949	27.6920173
1.0000000	1.0000000	1.0000000	0.

REYNOLDS= 0.2500000 PRANDTL= 0.7500000 DELTA=16.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0210828	-0.
0.0333333	0.0389061	-0.0223391	-0.0021237
0.0666667	0.0766835	-0.0203560	-0.0042783
0.1000000	0.1133944	-0.0150637	-0.0064674
0.1333333	0.1491061	-0.0064387	-0.0086940
0.1666667	0.1838919	0.0055050	-0.0109603
0.2000000	0.2178288	0.0207218	-0.0132679
0.2333333	0.2509978	0.0391398	-0.0156178
0.2666667	0.2834826	0.0606643	-0.0180102
0.3000000	0.3153697	0.0851819	-0.0204449
0.3333333	0.3467472	0.1125623	-0.0229210
0.3666667	0.3777049	0.1426616	-0.0254368
0.4000000	0.4083334	0.1753243	-0.0279901
0.4333333	0.4387241	0.2103847	-0.0305778
0.4666667	0.4689681	0.2476696	-0.0331959
0.5000000	0.4991566	0.2869991	-0.0358395
0.5333333	0.5293797	0.3281887	-0.0385023
0.5666667	0.5597263	0.3710506	-0.0411768
0.6000000	0.5902836	0.4153957	-0.0438534
0.6333333	0.6211367	0.4610345	-0.0465202
0.6666667	0.6523676	0.5077792	-0.0491618
0.7000000	0.6840552	0.5554450	-0.0517579
0.7333333	0.7162742	0.6038528	-0.0542809
0.7666667	0.7490944	0.6528298	-0.0566907
0.8000000	0.7825800	0.7022134	-0.0589261
0.8333333	0.8167885	0.7518522	-0.0608849
0.8666667	0.8517690	0.8016114	-0.0623764
0.9000000	0.8875613	0.8513743	-0.0629875
0.9333333	0.9241923	0.9010523	-0.0615986
0.9666667	0.9616748	0.9505878	-0.0537902
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 0.5000000 PRANDTL= 0.7500000 DELTA=16.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0235685	-0.
0.0333333	0.0343279	-0.0297502	-0.0047781
0.0666667	0.0677040	-0.0323059	-0.0096852
0.1000000	0.1002058	-0.0310988	-0.0147292
0.1333333	0.1319166	-0.0260800	-0.0199156
0.1666667	0.1629281	-0.0172615	-0.0252481
0.2000000	0.1933350	-0.0047016	-0.0307284
0.2333333	0.2232373	0.0115075	-0.0363568
0.2666667	0.2527367	0.0312457	-0.0421320
0.3000000	0.2819377	0.0543720	-0.0480511
0.3333333	0.3109456	0.0807279	-0.0541099
0.3666667	0.3398669	0.1101415	-0.0603024
0.4000000	0.3688079	0.1424301	-0.0666212
0.4333333	0.3978749	0.1774027	-0.0730569
0.4666667	0.4271727	0.2148622	-0.0795980
0.5000000	0.4568053	0.2546078	-0.0862309
0.5333333	0.4868741	0.2964364	-0.0929389
0.5666667	0.5174784	0.3401449	-0.0997019
0.6000000	0.5487140	0.3855318	-0.1064955
0.6333333	0.5806731	0.4323993	-0.1132893
0.6666667	0.6134433	0.4805553	-0.1200448
0.7000000	0.6471071	0.5298154	-0.1267114
0.7333333	0.6817409	0.5800053	-0.1332206
0.7666667	0.7174143	0.6309633	-0.1394738
0.8000000	0.7541887	0.6825435	-0.1453199
0.8333333	0.7921162	0.7346189	-0.1505061
0.8666667	0.8312384	0.7870857	-0.1545603
0.9000000	0.8715838	0.8398684	-0.1564552
0.9333333	0.9131659	0.8929282	-0.1533958
0.9666667	0.9559800	0.9462736	-0.1343204
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 1.0000000 PRANDTL= 0.7500000 DELTA=16.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0217448	-0.
0.0333333	0.0280723	-0.0359402	-0.0089308
0.0666667	0.0553788	-0.0461512	-0.0183275
0.1000000	0.0820170	-0.0521783	-0.0282121
0.1333333	0.1080909	-0.0539507	-0.0386012
0.1666667	0.1337151	-0.0514691	-0.0495076
0.2000000	0.1590070	-0.0447835	-0.0609408
0.2333333	0.1840909	-0.0339768	-0.0729073
0.2666667	0.2090931	-0.0191581	-0.0854110
0.3000000	0.2341440	-0.0004552	-0.0984530
0.3333333	0.2593754	0.0219876	-0.1120319
0.3666667	0.2849218	0.0480143	-0.1261431
0.4000000	0.3109180	0.0774582	-0.1407787
0.4333333	0.3375003	0.1101451	-0.1559274
0.4666667	0.3648046	0.1458945	-0.1715736
0.5000000	0.3929666	0.1845224	-0.1876966
0.5333333	0.4221208	0.2258425	-0.2042699
0.5666667	0.4524001	0.2696687	-0.2212593
0.6000000	0.4839351	0.3158167	-0.2386205
0.6333333	0.5168528	0.3641072	-0.2562959
0.6666667	0.5512765	0.4143674	-0.2742090
0.7000000	0.5873242	0.4664351	-0.2922554
0.7333333	0.6251078	0.5201609	-0.3102866
0.7666667	0.6647318	0.5754128	-0.3280820
0.8000000	0.7062917	0.6320797	-0.3452910
0.8333333	0.7498722	0.6900780	-0.3613108
0.8666667	0.7955455	0.7493556	-0.3749872
0.9000000	0.8433679	0.8099041	-0.3837616
0.9333333	0.8933779	0.8717635	-0.3805796
0.9666667	0.9455904	0.9350546	-0.3372826
1.0000000	1.0000000	1.0000000	-0.

FORM 1413-144 x 11 - 9 LINES PER INCH Continuous Interfold © Moore Business Forms, Inc.

REYNOLDS= 2.0000000 PRANDTL= 0.7500000 DELTA=16.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0148608	0.
0.0333333	0.0199428	-0.0363498	-0.0125377
0.0666667	0.0392905	-0.0545034	-0.0263736
0.1000000	0.0581404	-0.0690487	-0.0415997
0.1333333	0.0765992	-0.0798330	-0.0583033
0.1666667	0.0947867	-0.0867540	-0.0765697
0.2000000	0.1128306	-0.0897436	-0.0964836
0.2333333	0.1308700	-0.0887537	-0.1181295
0.2666667	0.1490518	-0.0837549	-0.1415918
0.3000000	0.1675338	-0.0747306	-0.1669551
0.3333333	0.1864823	-0.0616785	-0.1943035
0.3666667	0.2060740	-0.0446067	-0.2237208
0.4000000	0.2264947	-0.0235358	-0.2552895
0.4333333	0.2479405	0.0015049	-0.2890904
0.4666667	0.2706168	0.0304755	-0.3252013
0.5000000	0.2947390	0.0633292	-0.3636956
0.5333333	0.3205321	0.1000109	-0.4046401
0.5666667	0.3482302	0.1404621	-0.4480918
0.6000000	0.3780765	0.1846200	-0.4940931
0.6333333	0.4103227	0.2324240	-0.5426637
0.6666667	0.4452282	0.2838154	-0.5937876
0.7000000	0.4830593	0.3387467	-0.6473919
0.7333333	0.5240879	0.3971826	-0.7033066
0.7666667	0.5685897	0.4591126	-0.7611910
0.8000000	0.6168426	0.5245540	-0.8203834
0.8333333	0.6691231	0.5935712	-0.8795695
0.8666667	0.7257041	0.6662807	-0.9359645
0.9000000	0.7868474	0.7428853	-0.9829463
0.9333333	0.8528009	0.8236813	-1.0013992
0.9666667	0.9237842	0.9091512	-0.9129018
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 4.0000000 PRANDTL= 0.7500000 DELTA=16.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	0.	-0.0059633	0.
0.0333333	0.0117281	-0.0246123	-0.0106596
0.0666667	0.0230693	-0.0422769	-0.0235558
0.1000000	0.0340609	-0.0586888	-0.0390039
0.1333333	0.0447510	-0.0736437	-0.0573434
0.1666667	0.0552001	-0.0869301	-0.0789450
0.2000000	0.0654821	-0.0983382	-0.1042146
0.2333333	0.0756859	-0.1076386	-0.1335969
0.2666667	0.0859183	-0.1145948	-0.1675794
0.3000000	0.0963051	-0.1189501	-0.2066956
0.3333333	0.1069958	-0.1204397	-0.2515294
0.3666667	0.1181646	-0.1187805	-0.3027190
0.4000000	0.1300161	-0.1136825	-0.3609616
0.4333333	0.1427870	-0.1048402	-0.4270178
0.4666667	0.1567526	-0.0919437	-0.5017166
0.5000000	0.1722291	-0.0746700	-0.5859607
0.5333333	0.1895812	-0.0526940	-0.6807314
0.5666667	0.2092251	-0.0256781	-0.7870928
0.6000000	0.2316370	0.0067184	-0.9061947
0.6333333	0.2573572	0.0448525	-1.0392708
0.6666667	0.2869995	0.0890914	-1.1876288
0.7000000	0.3212555	0.1398334	-1.3526214
0.7333333	0.3609056	0.1975067	-1.5355769
0.7666667	0.4068230	0.2626049	-1.7376404
0.8000000	0.4599854	0.3356957	-1.9594027
0.8333333	0.5214777	0.4174826	-2.1999982
0.8666667	0.5925029	0.5088324	-2.4547006
0.9000000	0.6743782	0.6108932	-2.7075965
0.9333333	0.7685426	0.7251619	-2.9037666
0.9666667	0.8765302	0.8538031	-2.7951494
1.0000000	1.0000000	1.0000000	-0.

REYNOLDS= 8.0000000 PRANDTL= 0.7500000 DELTA=16.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	-0.	-0.0011822	-0.
0.0333333	0.0057847	-0.0082555	-0.0047070
0.0666667	0.0114873	-0.0164065	-0.0112616
0.1000000	0.0171349	-0.0248770	-0.0202106
0.1333333	0.0226981	-0.0341278	-0.0321711
0.1666667	0.0281580	-0.0438292	-0.0479140
0.2000000	0.0335088	-0.0541839	-0.0683569
0.2333333	0.0387229	-0.0649198	-0.0946162
0.2666667	0.0438071	-0.0760718	-0.1280237
0.3000000	0.0487453	-0.0873237	-0.1701792
0.3333333	0.0535651	-0.0985469	-0.2229826
0.3666667	0.0582836	-0.1093201	-0.2886952
0.4000000	0.0629721	-0.1193349	-0.3699866
0.4333333	0.0677127	-0.1280214	-0.4700102
0.4666667	0.0726610	-0.1348738	-0.5924680
0.5000000	0.0780151	-0.1391461	-0.7417058
0.5333333	0.0840797	-0.1401292	-0.9228026
0.5666667	0.0912490	-0.1368940	-1.1416967
0.6000000	0.1000776	-0.1285385	-1.4053129
0.6333333	0.1112797	-0.1139583	-1.7217409
0.6666667	0.1258134	-0.0920726	-2.1004248
0.7000000	0.1449018	-0.0615915	-2.5524262
0.7333333	0.1701416	-0.0212119	-3.0906882
0.7666667	0.2035537	0.0306763	-3.7303279
0.8000000	0.2477361	0.0958630	-4.4886359
0.8333333	0.3059607	0.1767923	-5.3841442
0.8666667	0.3824076	0.2765926	-6.4317626
0.9000000	0.4823387	0.3999912	-7.6230667
0.9333333	0.6124957	0.5536477	-8.8358018
0.9666667	0.7813827	0.7483286	-9.2770065
1.0000000	1.0000000	1.0000000	0.

REYNOLDS=16.0000000 PRANDTL= 0.7500000 DELTA=16.0000000

VARIABLE X	TAN.VEL. H	RAD.VEL. G	TEMP.FN. F
0.	-0.	0.0007636	-0.
0.0333333	0.0022095	0.0028920	0.0056211
0.0666667	0.0048039	0.0074637	0.0127098
0.1000000	0.0076035	0.0117509	0.0219521
0.1333333	0.0107191	0.0172228	0.0338159
0.1666667	0.0141901	0.0230363	0.0490512
0.2000000	0.0180532	0.0297645	0.0684631
0.2333333	0.0223872	0.0369755	0.0930787
0.2666667	0.0272302	0.0448509	0.1240429
0.3000000	0.0326624	0.0530209	0.1626784
0.3333333	0.0387261	0.0613603	0.2103730
0.3666667	0.0454838	0.0693722	0.2685146
0.4000000	0.0529597	0.0766018	0.3382511
0.4333333	0.0611692	0.0823010	0.4201769
0.4666667	0.0700749	0.0856690	0.5137548
0.5000000	0.0795960	0.0856978	0.6164759
0.5333333	0.0895739	0.0813744	0.7225429
0.5666667	0.0997745	0.0716972	0.8209736
0.6000000	0.1098739	0.0559522	0.8928416
0.6333333	0.1194862	0.0339351	0.9074403
0.6666667	0.1282151	0.0063827	0.8170196
0.7000000	0.1357888	-0.0246031	0.5498510
0.7333333	0.1423007	-0.0550229	0.0013905
0.7666667	0.1486417	-0.0785711	-0.9762979
0.8000000	0.1572017	-0.0863927	-2.5860194
0.8333333	0.1729821	-0.0672812	-5.0949405
0.8666667	0.2052688	-0.0083172	-8.8332297
0.9000000	0.2700752	0.1043441	14.1477305
0.9333333	0.3935577	0.2863219	21.1328838
0.9666667	0.6165921	0.5627512	27.7073863
1.0000000	1.0000000	1.0000000	0.

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