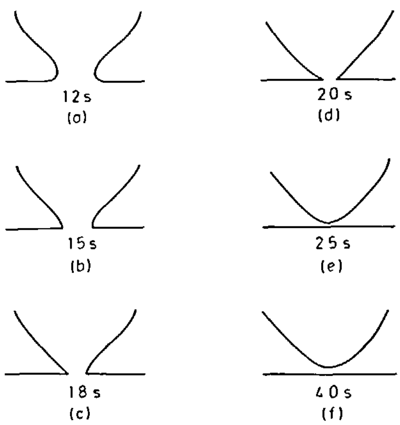

FIG 2 Spherical ball bearing above a plane wall photographed through a temperature field which is decaying in a complicated way at times t shown

DEPARTURE OF BUBBLES

During the growth and departure of a bubble at a wall the impossibility of observing the base of the bubble may prevent observation of the actual detachment of that base from the wall What appears to be detachment may in fact occur when the base of the bubble breaks through the top of the thermal boundary layer It may appear then that the bubble is connected to the wall by a neck, which thins down and breaks off apparently allowing the bubble to depart while part of the neck is left behind to retreat back to the wall But what is really happening may be that a complete bubble had in fact already detached from the wall and it is now passing through the stages of Fig 1(b) then Fig 1(a) as it moves away from the equivalent mirror at the top of the thermal boundary layer It is not easy to determine which explanation is correct since the normal technique of looking in the obvious direction (from the side) is fundamentally prevented when R_p is small compared with the size of the bubble Sonic investigation would meet the same problem Optical investigation from below would be an unwelcome complication and is generally not so effective Detailed analysis would require knowledge of the temperature field not usually available in boiling

CONCLUSIONS

When interpreting movies of bubbles at a hot wall in boiling the possibility of a mirage should be borne in mind and a useful rough guide may be obtained by the simple calculation of R_p for comparison with the distance light travels through the temperature gradient

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NOTE ON THE PULSATING NATURE OF THERMALLY-DRIVEN OPEN CAVITY FLOW

K S CHEN, J A C HUMPHREY and L MILLER
Department of Mechanical Engineering
University of California Berkeley CA 94720 U S A

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THERMALLY DRIVEN laminar and turbulent flows arise frequently in numerous configurations and shapes of engineering interest A literature review [1] shows that the heated flat plate and the rectangular enclosure are among the shapes most extensively investigated Recently the heated open cavity configuration has also become the object of intense and concerted research in relation to for example the ventilation of rooms and corridors [2] the spread of flames and smoke in buildings [3] and the evaluation of convective losses from solar thermal central receiver systems [1 4]

With the view in mind of extending the transient 2 dim laminar flow calculation procedure described in ref [5] to the turbulent flow regime we have been concerned with obtaining a clearer understanding of the nature of thermally driven turbulent flow in a strongly heated open cavity of rectangular cross section The purpose of this note is to report some significant findings concerning the pulsating nature of this flow for certain conditions A more detailed exposition of these findings including measurements of temperature in the cavity configuration is available [6]

For the purposes of this study an experimental apparatus has been constructed as explained in ref [1] The flow test section shown in Fig 1 is an open rectangular cavity of variable aspect ratio (a/b) and orientation angle (α) $a/b = 0$ corresponds to zero cavity depth (flat plate conditions) and $\alpha = 0$ corresponds to an orientation with the cavity aperture

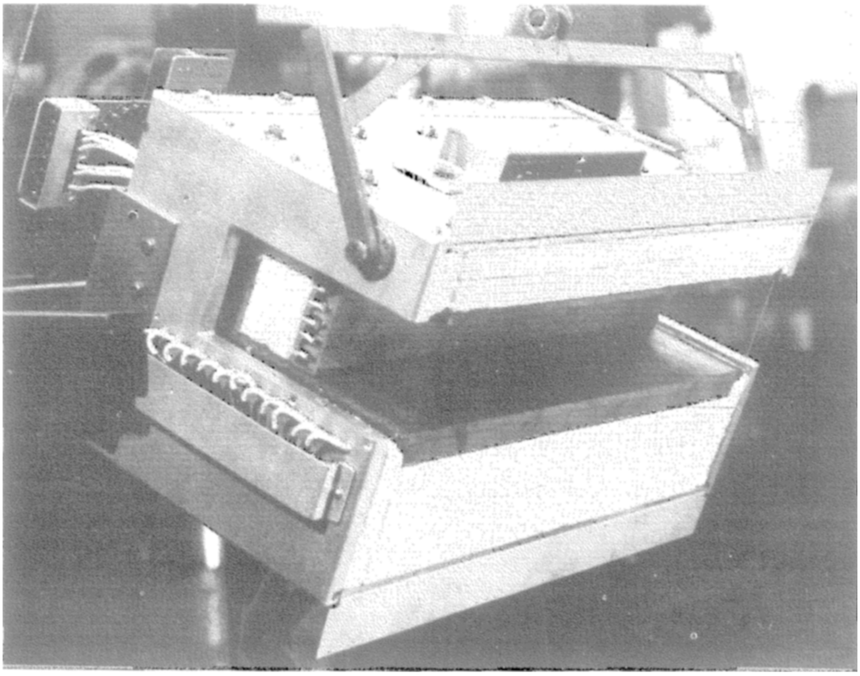

FIG 1 Photograph of experimental test section

plane and back wall aligned parallel with the gravity vector In the test section b the opening height and L the opening spanwise dimension are fixed such that $b = 9\ 4$ cm and $L/b = 5\ 7$ The cavity aspect ratio and orientation angle can be varied continuously between $0 \leqslant a/b \leqslant 1\ 58$ and $-60 \leqslant \alpha \leqslant 60$ The three inside walls of the cavity are thick copper plates which can be kept separately at conditions of uniform temperature and are continuously monitored with Chromel-Alumel thermocouple probes as described in ref [1] The ends of the cavity are covered with 1/8 in thick borosilicate glass plates to delimit the air flow in the cavity while allowing its probing by means of optical techniques An overall cavity wall temperature T_c was defined by averaging the mean temperatures at the three inside copper walls A film temperature was defined as $T_f = (T_c + T_\infty)/2$ and a Grashof number by $Gr = gb^3(T_c - T_\infty)/\nu_f^2 T_f$

Flow visualization using smoke and the shadowgraph technique and measurements of the mean temperature distribution at various locations in the cavity have been performed for the free convection regime in a room with still air at $T_\infty = 293$ K In the first of two sets of flow visualization experiments wall temperatures were slowly and evenly increased at the inside cavity wall thus inducing a quasi steady flow of air within the cavity At a value $(T_c - T_\infty)/T_\infty \simeq 0\ 31$ corresponding to a $Gr \simeq 6 \times 10^6$ in a cavity with $a/b = 1$ and $\alpha = 0$ the streamlined flow became unstable along the bottom wall The instability originated near the aperture plane corner and took the form of a periodic pulsation with a frequency of about 1 Hz At $(T_c - T_\infty)/T_\infty \simeq 0\ 44$ the pulsations in this configuration were more irregular but occurred at a rate of approximately 2 Hz The pulsations took the form of organized 2 dim eddies which in moving along the bottom wall towards the back wall of the cavity would simultaneously rise due to their buoyancy The pulsations were found to correlate with gentle surges in the flow of air leaving the cavity which appeared to be of a more turbulent nature A small amount of inclination ($\alpha \simeq 20$) was observed to dampen small scale fluctuations in the flow considerably to the point where for $\alpha = 45$ it reverted to a streamlined condition throughout most of the cavity However as shown in Fig 2 large scale periodic pulsations persisted in the flow leaving a cavity with $a/b = 1$ and $\alpha = 20$

A second set of visualization experiments was performed for cavity flows in the fully turbulent regime These flows were characterized by values of $(T_c - T_\infty)/T_\infty \simeq 1\ 37$ and $Gr \simeq 4\ 8 \times 10^6$ respectively Experimental runs were con

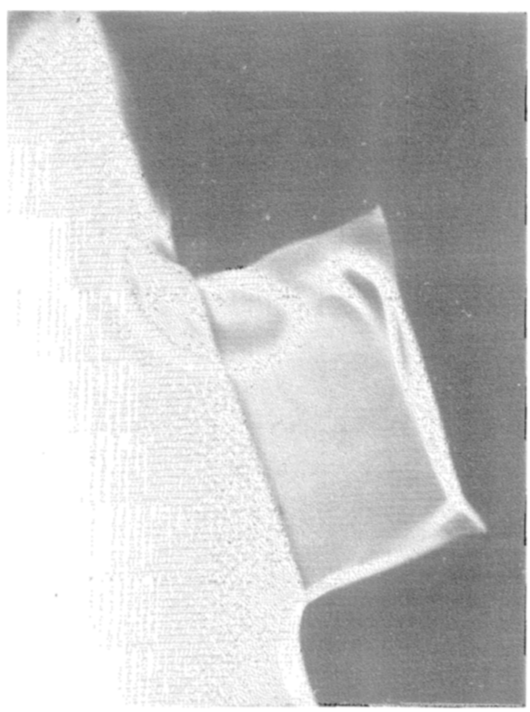

FIG 2 Large scale pulsations in a heated cavity with $a/b = 0\ 5$ $\alpha = 20$ and $Gr \simeq 6 \times 10^6$

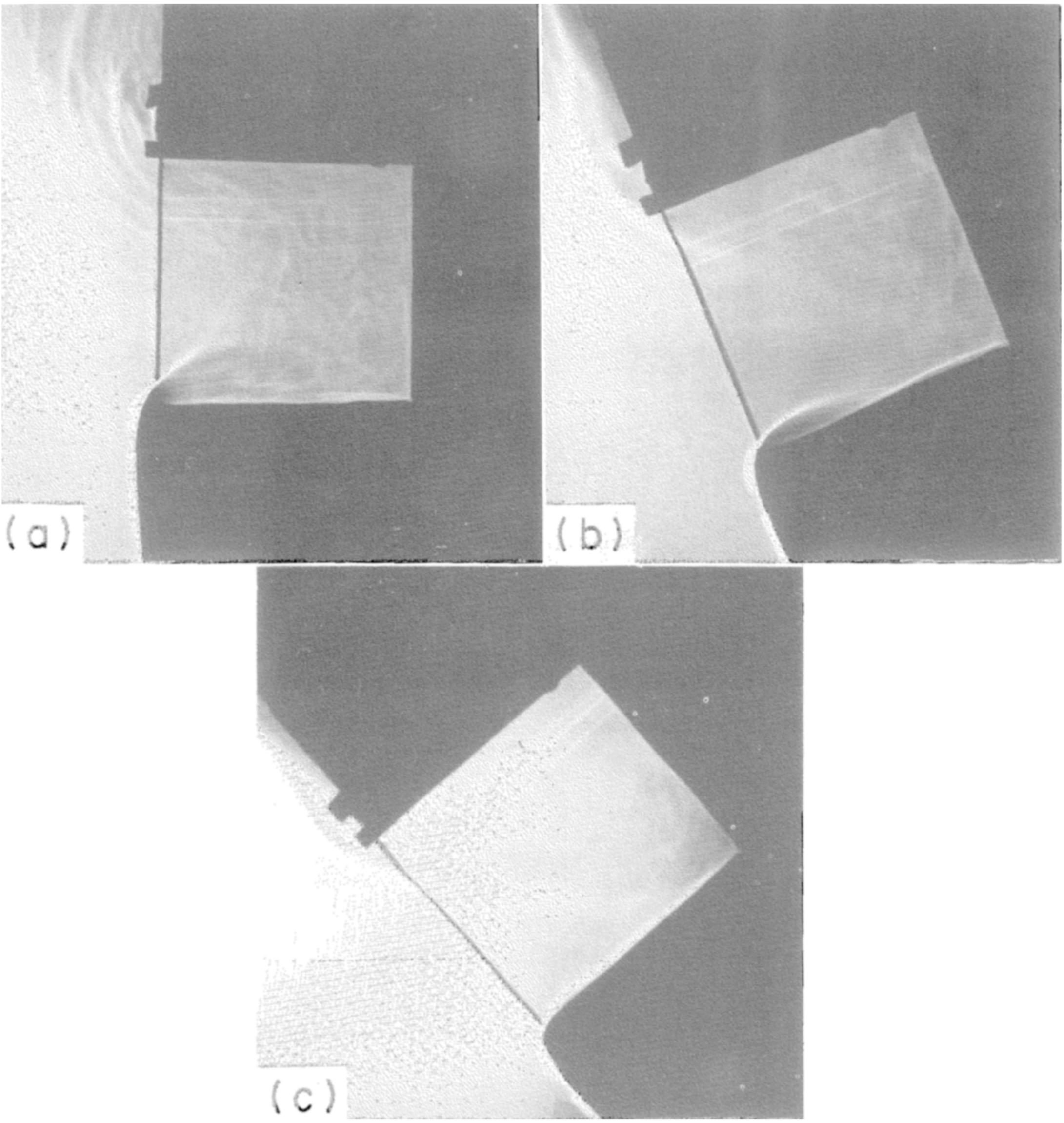

FIG. 3. Photographic sequence illustrating flow stratification and dampening of turbulence with increasing of α in a cavity with $a/b = 1, (T_c - T_\infty)/T_\infty = 1.37$ and $Gr \simeq 4.8 \times 10^6$; $\alpha = 0°$ in (a); $\alpha = 20°$ in (b) and $\alpha = 45°$ in (c).

ducted for $a/b = 0.5$, 1 and 1.58 and $\alpha = 0$, 20 and 45°. The sequence in Fig. 3 shows the appearance of the thermal boundary layer on the bottom wall of a cavity with $a/b = 1$ for orientation angles of $\alpha = 0$, 20 and 45°. At $\alpha = 0°$, the boundary layer separated strongly at the bottom wall entrance corner and reattached about halfway along this wall. The reattachment point oscillated erratically about this location. The entrance corner and the mean reattachment point delimited a region of strong clockwise-recirculating flow of oscillating size from which variously sized eddies were irregularly ejected into the cavity. As a consequence, the bulk of the flow within the cavity appeared well-mixed and turbulent in nature. With increasing α the bottom wall recirculation zone became smaller as the reattachment position was displaced towards the entrance corner as shown in Figs. 3(b) and (c). While thermal stratification of the flow in the cavity dampened considerably the buoyancy-driven turbulent activity throughout the bulk of the flow, particularly for $\alpha = 45°$, near the bottom and back wall surfaces turbulent-like motions were clearly visible for all α. Similar results but differing in detail were found for cavities with $a/b = 0.5$ and 1.58, respectively. However, two features were noteworthy: (a) in the shallow cavity ($a/b = 0.5$) the point of reattachment occurred at a mean position about 1/3 of the way up along the cavity back wall; (b) for all α, the cavity shape yielding the most intense buoyancy-driven turbulence activity (as judged by flow visualization) was that with $a/b = 1.58$.

It should be remarked that none of the turbulent flow configurations displayed clearly the organized low-frequency pulsations observed at the lower temperatures. Only more careful probing of the flow, preferably using a spectral analysis technique monitoring temperature and/or velocity at different locations in the cavity, will confirm or negate the presence of these pulsations at higher temperatures.

Measurements of transverse mean temperature profiles on the cavity symmetry plane [6] showed that for any given aspect ratio a/b, and to within the uncertainty of the measurements, the aperture plane temperature profile was not a strong function of the inclination angle α. However, for a fixed inclination angle the thermal layer at the cavity top wall increased in thickness with increasing aspect ratio. This was particularly noticeable in the profiles taken with $\alpha = 45°$. Inflexion points in the temperature profiles taken inside cavities with $\alpha = 45°$, and $a/b = 1$ and 1.48 respectively, attested to the presence of a counterclockwise-recirculating motion in the stratified flow region within the cavity. This recirculation was confirmed by the flow visualization results.

The present note is imperfect in the sense that detailed quantitative bounds are not provided for the dimensionless parameters governing the behavior of pulsating thermally-driven cavity flow. For this, continued experimentation is necessary and is currently underway. Nevertheless, the information advanced herein is timely and points to a phenomenon which has not previously been observed and may be present in the work of others.

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TEMPERATURE DISTRIBUTION IN A LARGE CIRCULAR PLATE HEATED BY A DISK HEAT SOURCE

R. C. Mehta

Aerodynamics Division (ARD), Vikram Sarabhai Space Centre, Trivandrum 695 022, India

and

T. K. Bose

Department of Aeronautical Engineering, Indian Institute of Technology, Madras 600 036, India

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NOMENCLATURE

- b, thickness of circular plate;
- $E(\ )$, complete elliptic integral of the second kind;
- $F(\ )$, hypergeometric function;
- $J_i(\ )$, Bessel function of the first kind;
- $K(\ )$, complete elliptic integral of the first kind;
- k, thermal conductivity;
- q, heat flux;
- r, radial coordinate;
- r_0, radius of heated area;
- T, temperature;
- T_w, temperature of coolant;
- z, axial coordinate.

Greek symbols

- θ, temperature rise, $T - T_w$;
- ∇^2, Laplace operator;
- $\xi(n)$, Riemann's zeta function;
- $\Gamma(m)$, gamma function.

INTRODUCTION

The heat transfer analysis of disk-shaped heating of a large solid plate is commonly required in spot welding, fire safety, the anode and cathode of an MPD arc, the cooling of electronic equipment and for electric circuit breakers. Thomas [1] gave an exact solution in terms of tabulated functions for a semi-infinite body heated by a constant heat flux in the region $0 \leqslant r \leqslant r_0$ at $z = 0$, with the other surface insulated. The purpose of the present note is to consider the isotherm at $z = b$, and to determine the effect of plate thickness on the temperature distribution. The solution derived is for the steady state heat conduction problem. This solution is useful in the development of a new series solution [2, 3] for transient temperature in a solid where the solution at the surface takes advantage of a known steady state solution.

ANALYSIS

The circular plate is considered to be isotropic and homogeneous. The geometry and coordinate are shown in Fig.