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HEAT TRANSFER MECHANISM IN RECIRCULATING WAKES

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NOMENCLATURE

- a, equatorial radius of oblate spheroid;
- c_p, thermal capacity;
- h, local heat transfer coefficient;
- k, thermal conductivity;
- $Nu(\eta)$, local Nusselt number $= 2\,a\,h/k$;
- Pr, Prandtl number, $c_p\mu/k$;
- Re, Reynolds number $= 2\,a\rho U/\mu$;
- T, normalized local temperature;
- U, dimensional velocity of the undisturbed fluid at infinity;
- v, dimensionless local velocity $= v'/U$;
- v', dimensionless local velocity of the fluid.

Greek letters

- η, spheroidal coordinates, angle;
- μ, viscosity;
- ξ, spheroidal coordinate orthogonal to η;
- ρ, density;
- ψ, dimensionless stream function $= \psi'/aU^2$;
- ψ', dimensional stream function.

Subscripts

- a, spheroidal surface;
- η, η- direction;
- ξ, ξ- direction.

THE FLOW of a Newtonian incompressible fluid past an oblate spheroid at intermediate Reynolds number ($\simeq 100$) is characterized by the appearance of a steady axisymmetric recirculating wake which is attached to the downstream side of the spheroid, Rimon and Lugt [1] and Masliyah and Epstein [2].

When the spheroid surface is at a higher temperature than the ambient fluid, heat is transferred to the fluid. The role of the wake in the heat transfer is best demonstrated by the solution of the equations governing the fluid motion and the heat transfer.

The energy equation for forced convection with constant fluid properties, in oblate spheroidal coordinates (ξ, η) is

$$v_\xi\frac{\partial T}{\partial \xi} + v_\eta\frac{\partial T}{\partial \eta} = \frac{2\cosh\xi_a}{Pr\,.\,Re(\cosh^2\xi - \sin^2\eta)^{\frac{1}{2}}}\left(\frac{\partial^2 T}{\partial \xi^2} + \frac{\partial^2 T}{\partial \eta^2} + \cot\eta\frac{\partial T}{\partial \eta} + \tanh\xi\frac{\partial T}{\partial \xi}\right).$$

The velocity components v_ξ and v_η are given by the numerical solution of the momentum equations for steady axisymmetric flow [2]. The boundary conditions employed are $T = 1$ at the surface of the spheroid ($\xi = \xi_a$), $T = 0$ at $\xi \to \infty$ and $\partial T/\partial\eta = 0$ at $\eta = 0$ and π. The solution of the energy equation was accomplished by using central finite difference equations, Masliyah and Epstein [3].

The closed recirculating streamlines inside the wake, together with the isotherms, as obtained by the complete solution of the motion and energy equations reveal a rather interesting mechanism of heat transfer. The fluid in the wake enclosed by the streamline $\psi = 0$ in Fig. 1 does not leave the recirculating wake, by definition of a streamline. It follows that the heat emanating from that portion of the spheroid surface surrounded by the wake is ultimately transferred by conduction across the streamline $\psi = 0$. A hot element of fluid situated near the surface on one of the closed streamlines, say $\psi = -0{\cdot}01$, loses its heat on its

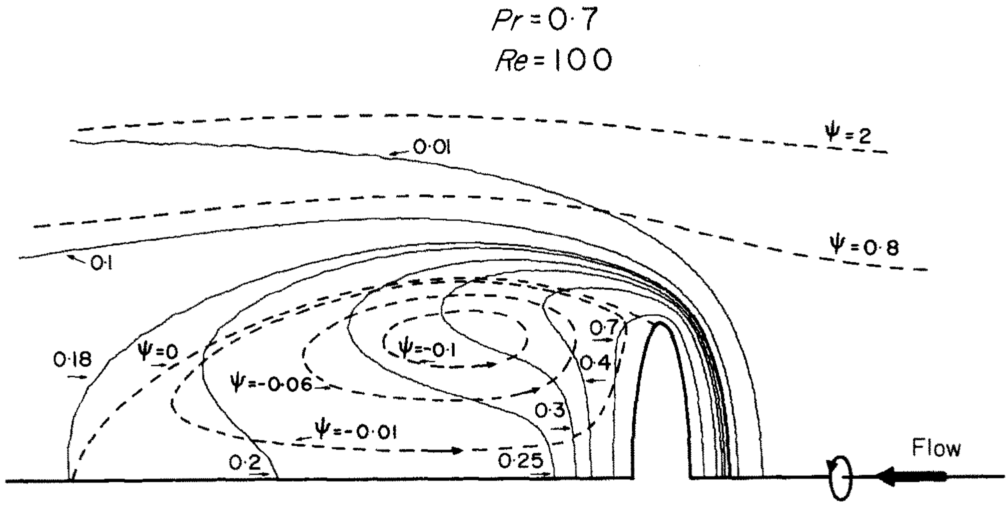

FIG. 1. Streamlines (dashed lines) and isotherms (solid lines) for an oblate spheroid with a ratio of minor to major axis of 0·2.

journey away from the surface, as indicated by the isotherms for $Re = 100$ and $Pr = 0{\cdot}7$ (air). On its return journey its temperature rises as it approaches the spheroid surface. This element of fluid thus acts as a carrier of heat from the spheroid heat source to the external flow heat sink. Heat from the surface of the spheroid is convected almost to the wake boundary, whence it is conducted to the external flow and carried downstream by the fluid outside the wake.

These "convecting currents" consequently increase the local surface Nusselt number within the wake, as shown in Fig. 2 for the case of $Re = 100$ and $Pr = 0{\cdot}7$. For comparison, the case of a creeping flow with $Re \,.\, Pr = 70$ is also plotted. This type of flow does not give rise to any recirculating wake, and consequently the value of Nusselt number at the rear end of the spheroid is very close to that for the case of pure conduction.

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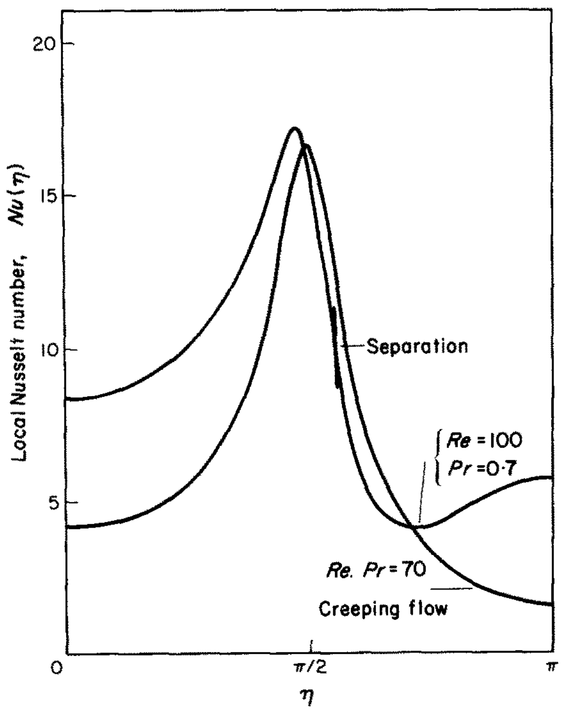

FIG. 2. Distribution of local surface Nusselt number for an oblate spheroid with a ratio of minor to major axis of 0·2.