Int. J. Heat Mass Transfer. Vol. 5, pp. 1023–1050. Pergamon Press 1962. Printed in Great Britain.

HEAT TRANSFER, A REVIEW OF CURRENT LITERATURE

E. R. G. ECKERT,* T. F. IRVINE, Jr.,† E. M. SPARROW* and W. E. IBELE*

Heat Transfer Laboratory, University of Minnesota, Minneapolis 14, Minnesota

(*Received* 4 *June* 1962)

INTRODUCTION

THIS review covers the results of research in the field of heat transfer which have been published during the foregoing year. Many present-day engineering developments lean heavily on the solution of heat-transfer problems; correspondingly, the research activity in this field continued to be strong, and this review can include only a selection of the papers which have been published. A more complete listing of papers in the field of heat and mass transfer is contained in the "Heat Transfer Bibliographies" published periodically in this magazine.

A number of large conferences were held during the past year which were devoted to a discussion of heat-transfer research. A conference held at Minsk, B.S.S.R., from June 5 to 9, gathered over 700 attendants from the Soviet Union and a number of guests from other countries. Over 300 papers were presented. A few of them have been published in English translation in a special issue of this journal and a larger collection will be issued in book form by Pergamon Press. Another conference on heat transfer with international participation was held in Paris during the second half of June. The Heat Transfer Laboratory of the University of Minnesota presented an extension course "Modern Developments in Heat Transfer" in which eleven speakers from abroad and from the United States discussed the results of recent research. The lectures will also be published shortly in book form by Academic Press. The highlight of the past year was an International Conference on Heat Transfer which was held August 28 to September 1 at Boulder, Colorado, with a continuation in London, January 8 through 12, 1962. This conference brought together a large international group of authors and attendants. One hundred and twenty-four papers had been preprinted and were discussed at both meetings. These papers are conveniently available as preprints in five volumes and will be published in the near future together with the discussions in book form by The American Society of Mechanical Engineering. Therefore they have not been included in this review. A considerable number of new books either are devoted to the field of heat transfer or contain chapters dealing with it or with properties needed for heat-transfer calculations (List 1 in reference section).

A very large effort has gone during the past year into the calculation of various heat conduction situations. The many published solutions include composite bodies, moving boundaries, and changes of phase. These solutions are obviously to a good part motivated by the ablation cooling process which has become the standard method of cooling re-entering missiles and satellites and which is being developed for rocket nozzle cooling. Papers in this area also include studies of the boundary layer and the possible use of a liquid or charred layer in addition to the solid wall material.

In convective heat transfer, special attention was given analytically as well as experimentally to vortex flow, largely as a consequence of the efforts to contain a nuclear fission process in a vortex chamber. Analyses of boundary layer flow have focused attention on approximate procedures, whereas only few new exact solutions have been published. Magnetohydrodynamic situations, chemical reactions in the boundary layer, and ionization have found interest analytically and experimentally. The influence of Lewis number was studied specifically

---

* Professor of Mechanical Engineering.

† Dean of Engineering, State University of New York, Long Island Center, Oyster Bay, New York.

in this connection. Experimental studies on separated flow conditions attempted to understand the physical nature of this process for simple geometries and to develop analytical models which will allow the prediction of local heat transfer. The nature of transition to turbulence on smooth and rough surfaces is of basic importance for a prediction of heat transfer, and its study has continued during the past year and will certainly continue in the future. Heat transfer in boiling was one of the areas which has found the strongest attention. This, again, can be traced to the fact that boiling of a fluid offers a possibility to remove intense heat fluxes with small temperature differences and is therefore a desired cooling process in various engineering applications, including nuclear reactor development.

Interest has also been strong in the area of thermal radiation. Heat exchange as occurs in space applications has been under study, and special attention was given to heat transfer in the high-temperature boundary layer near the stagnation point of an object moving with hypersonic velocities where the layer between the shock and the surface contains a strongly-radiating gas. Radiation properties have been determined for many materials by measurements. Thermodynamic and transport properties for various gases at high temperatures, as determined through statistical mechanics, constitute a significant effort in this area.

CONDUCTION

Transient heat conduction and heat flow through non-homogeneous mediums received attention by many investigators.

Bergles *et al.* [6A], present general solutions, which when used with previously published charts, permit rapid, reasonable estimates of one-dimensional, transient, temperature distribution for time dependent boundary conditions. Further refinements [21A] enable the integral method to treat temperature dependent properties when considering transient heat conduction in a slab. For a linear change in the environment temperature, the internal temperature distribution of bodies has been solved graphically [56A]. Aerodynamic heating during vehicle re-entry is treated as one-dimensional heat conduction with an arbitrary, time dependent heat rate at one boundary, the other being insulated [10A]. In [24A], the temperature distribution for various plane bodies is examined when the adiabatic wall temperature, film coefficient, and radiant heat flux are time dependent. Specific temperature distributions during aerodynamic heating are given for an insulated thick skin [25A], for thin-skinned bodies [12A], and the design of insulated compression plates under such conditions treated in [13A]. Spence [49A] treats the case of a semi-infinite solid heated over its surface at a rate depending on location and time, and the problem of surface temperature variation at the stagnation point of a bluff body. Both problems have shock-tube application. Other specific inquiries lead to the formulation of transient heat conduction problems as in the case of fire [54A], the response of a thermocouple circuit [44A], and the heating of slabs in furnaces [27A, 19A]. For attacking transient heat-transfer problems, Duhne [16A] proposes an hydraulic analogue.

Steady, two-dimensional, temperature fields in a stratified semi-infinite medium is considered by Vodicka [57A], analytical solutions for the heat flow in slabs of various cross sections reported by Lu [38A], the method of conformal mapping illustrated by Schneeweiss [47A], and a simple method of calculating heat flow in such composite systems proposed by Stops [51A]. Consideration of the guarded hot plate used for measuring thermal conductivities leads to heat conduction in a two-layer system [15A]. The composite body problem finds geological expression in the flow of heat from a differentiated earth [11A].

The transient heating of a composite wall consisting of a good conductor over an insulator is solved and the eigen values reported [8A]. Transient heat flow across the plane contact surface of two semi-infinite bodies is considered in the familiar way [55A]. Transient heat conduction for systems undergoing phase change is considered by [52A] where the phase formed by sudden heating is removed and by [58A] where the solid–liquid interface may move or remain at rest. Rogers [45A] confirms contact resistance dependence on direction of heat flow. By an approximate analogy, Tien [53A] finds the solution of conduction through a non-homogeneous medium through known solutions for homogeneous cases. Thermal conductivities of heterogeneous materials are treated in [22A, 33A].

In the area of heat transfer with sources, [3A] investigates the simplest boundary condition for unsteady heat flow with the source depending exponentially upon the temperature. The temperature field for a cylindrical source in a half-limited block is given by Altshuler [1A] and the Binder–Schmidt procedure extended to the case of transient heat transfer with moving heat sources [37A]. Combined heat flow by conduction and convection from a cylindrical source of increasing radius is solved by Bailey [4A] for the cases of finite coefficients. Heat flow in hollow cylinders with internal heat generation is investigated for radial electric current flow [9A] and for eccentrically hollow cylinders with uniform heat generation [18A]. Johnson [29A] reduces the problem of heat transfer between moving fluid and solid boundaries to an equivalent one of heat conduction in a composite body with heat generation in one body. The axial temperature distribution in a nuclear reactor with space and time dependent power generation is considered in [14A], and the temperature distributions in reactor full element end caps discussed in [41A].

Konakov [32A] examines the regularities of the three modes of heat transfer, analysing the relations obtained for a number of particular cases. Conditions under which the two-dimensional conduction equation has solutions for specified boundary conditions is considered [31A] and the steady state temperature distribution in prismatic bars with isothermal boundary conditions reported by [5A]. Jordan [30A] describes an integral method of calculating boundary value problems in heat conduction for the cylindrical cavity and the half space, while Heyda [26A] treats the circular ring with a radiation boundary condition. The heat balance integral is applied to the problem of a cylindrical hole exposed to constant heat flux [34A].

The finite difference method is applied to three-dimensional, transient heat conduction problems [7A], stability criteria for uncommon boundary conditions discussed [36A], and an exchange reported [17A, 2A] regarding accuracy and computer time of difference schemes. A practical method of estimating truncation error associated with finite-difference forms of the heat conduction equation is given [20A] and Miranker [42A] discusses the heat conduction equation for the case where the solutions do not continuously depend on the initial data. Useful tables of the hyperbolic functions of $(1 + i)x$ are reported [50A] for one-dimensional, periodic heat conduction problems.

Heat conduction and thermal elasticity for a plane with an infinite number of groups of openings is studied [40A].

Cooling fins with heat generation are treated using the calculus of variations [35A] and the cooling of a tubular thrust chamber optimized as a fin problem [48A].

For insulating materials, the overall heat-transfer coefficients is related to coefficients associated with the specific heat transfer mechanisms and medium properties [46A] and the effectiveness of mineral wool combined with reflective surfaces measured [39A].

Anomalies in the temperature distribution in the surface layers of a heated or cooled wall are reported [28A], density fluctuations and heat conduction in a pure liquid examined by Nettleton [43A], and heat conduction in normal and superconducting tin and indium studied by Guenault [23A].

CHANNEL FLOW

Laminar heat transfer in ducts of various cross sections continues to be of analytical interest. The simultaneous development of the temperature and velocity distributions in the entrance region of a parallel-plate channel has been solved both for symmetric [47B] and unsymmetric [48B] thermal boundary conditions. The corresponding solution for the annular gap between two concentric cylinders has also been given [28B]. Leveque's boundary-layer solution for the thermal entrance region of tubes has been extended [41B] to include a finite wall resistance. As another extension of prior work, a closed-form expression for the tube Nusselt number is derived [32B] for longitudinal wall heat flux variations expressible as a polynomial.

Fully developed heat transfer solutions for non-circular ducts with uniform longitudinal heating were constructed [49B] by use of the methods of complex variables, and application is made to the equilateral triangle and the ellipse. Fully developed heat-transfer results have been calculated by more direct methods for concentric and unsymmetric annular gaps [15B, 23B, 53B], and for the longitudinal flow parallel to rods arranged in an equilateral-triangular array [46B]. For laminar flow at low Peclet (*Pe*) numbers, the heat-transfer results are affected by axial conduction. The magnitude of this effect becomes negligible when $Pe \geqslant 10$ for fully developed heat transfer in tubes [33B] and parallel plate channels [34B] with uniform wall temperature.

Solutions have been derived [36B] for laminar, incompressible heat transfer in a parallel-plate channel subjected to time-dependent thermal boundary conditions and time-dependent pumping pressure. Additional unsteady heat-transfer results for the channel are given [5B] for a heat-generating flow with time-varying inlet velocity or inlet temperature and prescribed heat-transfer coefficient between fluid and wall.

An exact solution has been devised [31B] for a one-dimensional, constant area, compressible gas flow with wall friction and longitudinally uniform heat addition. A study of chemically reacting, isothermal tube flow, formerly analysed for a single first-order reaction, has now been extended [55B] to include consecutive first-order chemical reactions. Several papers have appeared dealing with magnetohydrodynamic flow and heat transfer in ducts. Solutions for the thermal entrance region of parallel plate channels have been carried out both for uniform wall temperature [30B] and uniform heat flux [35B]. The fully developed solution for the uniform heat flux case has been extended [1B] to include the effects of finite electrical conductivity of the walls. In an interesting experimental study, it was found [11B] that an axial magnetic field retarded the transition from laminar to turbulent flow in a circular tube.

In contrast to the predominately analytical interest in laminar flow, the turbulent case has been treated both analytically and experimentally. The heat-transfer characteristics (excluding radiation) of a turbulently flowing mixture of gas and solid particles were predicted by analysis [52B]. A proposal has been made [17B] for modifying two aspects of Deissler's analogy for cases of large transverse density variations (e.g. fluids near the critical point). These involve a change in the eddy diffusivity expression and the use of a transverse shear stress distribution dependent on free convection. It has been demonstrated [44B] that Deissler's variable-property heat-transfer results for tubes can be rephrased as a function of T_b/T_w (T_b = bulk temperature, T_w = wall temperature) in lieu of the original, less physical parameter. Semi-empirical analyses involving modifications of the method of analogies have yielded predictions of the Nusselt number for unsymmetrical heating in a parallel-plate channel [3B] and in an annular gap [4B]. Surveys have been carried out of fully developed turbulent heat-transfer results in annular gaps [37B] and in circular tubes [54B]. The latter has proposed a single empirical formula for the tube Nusselt number for the entire Prandtl number range between 0·001 and 1000 for the Reynolds number range 2100 to 10^7. The relationships between dimensionless groups which arise in fully developed flow and heat transfer in tubes are discussed [45B].

Experiments on the turbulent flow of water in an annular gap (inner tube heated, outer tube insulated) show [18B] the presence of spoilers (turbulence promoters) to be quite advantageous. Additional data for the annular gap system without spoilers are given in [23B]. Measurements of laminar, transitional, and turbulent heat transfer in a circular tube attached to a supersonic nozzle are in qualitative agreement with flat plate theories [26B]. Turbulent friction factor data for isosceles-triangular ducts (opening angles up to 40°) fell below the circular tube results when correlated on a hydraulic diameter basis [8B]. A modification of the hydraulic diameter concept has been proposed [16B] to provide better predictions of non-circular duct performance. In a fundamental experimental study, measurements were made [2B] on the turbulent downstream diffusion of heat from a line source (hot wire) placed in the turbulent core of a fully developed tube flow. The diffusion results were in good agreement with the theory of G. I. Taylor.

Dissociation data for nitrogen dioxide flowing turbulently in a circular tube gave heat-transfer coefficients up to fourteen times as great as in a frozen (non-reacting) flow [22B]. In another experiment involving dissociation, a 6500°F gas flow generated in a plasma facility was utilized [7B]. Entrance region heat-transfer measurements in a refractory tube could be well-correlated by a conventional Stanton–Reynolds relation with a heat-transfer coefficient based on the wall-to-bulk enthalpy difference. At the other end of the temperature scale, energy transport in capillary tubes by liquid helium II has been measured [6B] in the transition regime to supercritical conduction.

There has been considerable recent interest in vortex flows. The theory of the vortex cavity (nuclear) reactor has been given [19B] and associated experiments carried out and interpreted [21B, 20B]. Temperature data [42B] in swirling flows confined in cylindrical chambers of low length–diameter ratios ($\leq 0{\cdot}5$) are suggestive of energy separation effects which are well-established in vortex tubes. Turbulence intensity and mean velocity distributions have been measured in a vortex tube and a cyclone separator [43B]. The angular velocity was found to be nearly constant at radii less than one-half the tube radius. Consideration of the flow and energy dynamics of the vortex tube led to the conclusion [38B, 39B] that the effect of all important transport processes is to transfer energy outward (i.e. toward larger radii). The generalization of a potential vortex to a vortex in a viscous, heat-conducting gas has been analytically carried through [25B].

Experiments have been carried out on fluctuating flows. For air flowing in a horizontal tube, impressed acoustic vibrations gave up to 51 per cent greater heat transfer in the laminar regime and 27 per cent greater in the turbulent regime [24B]. The Reynolds number range was 560–5900. Data taken for pulsating air and oil tube flows are found to be in satisfactory agreement with a semi-empirical theory [9B, 10B].

Non-Newtonian heat transfer and pressure drop were measured [50B] for aqueous thorium oxide flowing in a circular tube in the laminar, transition, and turbulent regimes. The turbulent heat-transfer data could be correlated by a suitable modification of Newtonian relationships. An analysis for the non-isothermal pressure drop in a non-Newtonian tube flow was carried out including a temperature-dependent shear law [14B]. Data for a large number of pseudoplastic solutions were in good agreement with the theory. The heat-transfer analysis for a viscous-dissipating Couette flow has been extended to non-Newtonian fluids [51B].

Two interesting measurement techniques appropriate to channel flow studies have been reported. In one [40B], two methods are described in which bulk velocities and temperatures can be found without resorting to traversing or to use of a mixing chamber. In the second [27B], a method is described for measuring the mean wall temperature and heat flux by essentially converting the wall itself into a series of resistance thermometers.

Variational methods for calculating laminar heat transfer in channels [13B] and in other flow systems [29B, 12B] have been formulated by extending Biot's concepts of thermal potential, dissipation function, and generalized thermal force.

BOUNDARY-LAYER FLOW

Boundary-layer solutions

Recent analytical work in boundary-layer theory strongly reflects current applications. An integral method has been devised [6C] for rapid calculation of the heat-transfer distribution on yawed cylinders of arbitrary cross section or on bodies of revolution in a laminar high-speed gas flow. By using a streamline co-ordinate system and the assumption of small cross flow, it is possible [5C] to reduce the governing equations for a laminar, three-dimensional, compressible, boundary-layer flow to those for an axisymmetric flow. The theorem is illustrated by application to the yawed cylinder. The laminar heat transfer to blunted cones at angle of attack has been calculated [53C] by integrating along the inviscid streamlines, taking into account the local fluid properties. The characteristics of a laminar, compressible boundary layer for strong favorable pressure gradient, insulated wall, and Prandtl number of one may be obtained from a recently proposed integral method [59C]. Another approximate method provides [55C] the local heat transfer from an isothermal surface to a constant property, laminar boundary layer with arbitrarily prescribed free stream velocity and Prandtl numbers in the range 0·7–10.

An approach [36C] to the dissociating turbulent boundary-layer flow over a flat plate has utilized a modified mixing-length concept in the turbulent core and retains the usual laminar sublayer. A transformation is proposed [11C] between compressible and incompressible boundary layers with heat transfer which provides local compressible skin friction results for both the laminar and turbulent regimes; the Prandtl number is restricted to unity. A new formulation of Reynolds analogy [26C] for turbulent boundary layer flow over a flat plate involves the power n in the velocity distribution $u/U_\infty = (y/\delta)^{1/n}$.

The transient heating of a wall by a supersonic boundary layer flow is analysed [46C] by utilizing the Chapman–Rubesin heat-transfer solution for non-uniform surface temperature. Another analysis [44C] has shown that deceleration forces may strongly influence the downstream flow of a liquid boundary layer formed by the melting of a heat shield. Local skin friction results on a surface in a boundary-layer flow may be measured with the help of a heated element embedded in the surface. In this connection, a solution has been obtained [49C] for the thermal boundary layer which develops from a heat source transverse to the flow direction embedded in a flat plate. A prediction [61C] of the effects of unsteady laminar, turbulent, or transitional boundary layers on the attenuation of shock waves in a shock tube has been verified by experiment.

A fundamental improvement in the Kármán–Pohlhausen method has been devised [67C]. Integrals of the profiles are taken over from the standard procedure, as is the variation of the boundary-layer thickness; utilizing these, a more accurate approximation of the profiles is calculated. A method of circumventing the trial and error aspects associated with solving the boundary-layer energy equations is outlined and applied [39C].

The time-dependent laminar heat transfer from a flat plate subject to a step-change in surface temperature has been calculated by patching together series solutions which apply for short and long times [10C]. The results are generalized by a superposition integral. Additionally, the time-variation of the surface heat transfer due to a small oscillation in the free stream flow has also been solved for [24C]. The thermal transient which occurs when a fluid above an infinite plane is set into impulsive motion has been analysed [31C]. The temperatures of the fluid and the bounding solid are unequal at the start of the transient period.

Extensive numerical (similarity) solutions [34C] provide laminar skin friction and heat transfer results for free stream velocities varying as x^m, wall blowing and suction velocities varying as $x^{(m-1)/2}$, and surface temperatures varying as x^n. The energy equation solutions were for a Prandtl number of 0·73. An approximate closed-form solution, numerically verified for Prandtl number of 0·7, has been derived [56C] for a stagnation-point flow in which there is a volume heat source proportional to the difference between the local and free stream fluid temperatures. Laminar heat-transfer results for fluids with temperature-dependent viscosity have been obtained by application of an integral method [27C]. The results have application to viscous liquids. Asymptotic solutions for high Prandtl-number, laminar boundary layers were derived [2C] by using the fact that the thermal boundary layer is much thinner than the viscous boundary layer. The Prandtl-number dependences of the recovery factor and Reynolds Analogy factor for the laminar boundary layer have been found [57C] by a series expansion method.

An interesting discussion [52C] of boundary layers on continuous surfaces points out departures from conventional flat plate boundary layers. The continuous surface might, for example, be a sheet extruded continuously from a die. It is found that the boundary layer on the sheet grows thicker in the direction of motion of the sheet.

Dissociation and chemical reactions

Considerable research has been done in the past year to study the effect of chemical reactions within the fluid or on the surface. Special attention has been directed towards the laminar stagnation boundary layer [3C, 14C, 35C, 38C].

Non-equilibrium dissociation and recombination in the viscous shock layer at the stagnation point may result in a significant reduction of the heat transfer to a non-catalytic wall under some flight conditions [14C]. Boundary-layer solutions for equilibrium dissociated air with variable Lewis number demonstrate that use of the mean Lewis number together with constant property relations leads to satisfactory approximations [3C]. The neglect of the variation of specific heat in a chemically frozen stagnation point boundary layer may lead to errors of order 20–30 per cent [29C]. A summarizing treatment of boundary-layer theory with dissociation and ionization for flat plate and stagnation point flow conditions has appeared in *Advances in Applied Mechanics* [38C].

An integral method was used to investigate heat transfer to a surface with finite catalytic activity exposed to frozen dissociated flow [15C]. Closed form solutions were obtained for flow with and without transpiration on a flat plate and the principle of local similarity worked well for other geometries. Solutions to the diffusion and energy equations for laminar boundary layer flows past two-dimensional surfaces of arbitrary geometry were obtained in closed form by an asymptotic development [1C]. A qualitative similarity exists between the velocity profile in a boundary layer with pressure gradient and the concentration and temperature profile with homogeneous reaction [28C]. The laminar continuity, momentum, energy, and concentration boundary-layer equations with heat and mass sources were analysed when the source strength depended on temperature [13C].

Dissociation effects on skin friction and heat transfer in a compressible turbulent boundary layer were analysed using a simplified model with a laminar sublayer [21C]. Specifically, the influence of a Lewis number different from one was investigated. Heat transfer for a fluid flowing turbulently through a tube and reacting with its surface is predicted to lead to heat-transfer coefficients up to ten times as large as the values without reactions [50C]. An increase of the same order of magnitude was measured in turbulent pipe flow of a chemically reacting fluid (N_2O_4, [30C]). The influence of chemical reactions on turbulent boundary-layer flow was also analysed in [37C].

Magnetohydrodynamics

Heat transfer to a surface in rotationally symmetric and two-dimensional stagnation flow as influenced by a magnetic field was analysed in several papers [41C, 47C, 66C]. Heat-transfer coefficients [41C] as well as recovery temperature [47C] decrease as the magnetic field increases. Experiments have been performed to study heat transfer by convection in the presence of a magnetic field in a layer of mercury bounded by two flat surfaces [42C]. The results of the study performed with a magnetic field strength of 1195–1820 G are in agreement with analytical prediction by Nakagawa. Magnetic drag on a body re-entering through an atmosphere has the effect that energy which ordinarily would be transferred to the vehicle is dissipated ohmically within the shock layer of the gas [45C], therefore, at larger distances from the surface. The heating effect on the body is in this way reduced. An electric field in a non-conducting liquid generates forces in regions with reduced dielectric constant (low density). Convection currents generated in this way are found to increase heat transfer from a hot wire to the surrounding liquid [62C]. A one-dimensional analysis of magnetohydrodynamic energy conversion investigates the basic process applied in magnetohydrodynamic power generators [19C]. Expressions for the power generated per unit volume, for the total temperature, and the pressure drop are derived for flow of a conducting fluid through channels with constant area and constant Mach number.

Experimental investigations

Measurements which were reported already in previous years indicated that in supersonic flow of air over a flat plate the transition Reynolds number at first increases with decreasing ratio of wall-to-free-stream temperature and then decreases again for very intensive cooling of the surface. A number of experiments and investigations verified this finding [17C, 20C, 40C, 48C]. Arguments are presented for the fact that this transition reversal is caused by surface roughness on one hand [48C] and that it is independent of roughness on the other hand [17C]. A study on a cone at Mach number 4 found a double reversal in the sense that at a fixed Reynolds number, and with decreasing ratio of wall-to-free-stream temperature, the boundary layer was at first laminar, then changed to turbulence, and back again to laminar flow [64C]. On a highly polished hemisphere-cone in free flight at Mach numbers up to 3·14 and Reynolds numbers to 24×10^6, critical Reynolds numbers for transition based on momentum thickness varied between 794 and 2190 [8C] depending on the amount of cooling. Several investigations considered transition to turbulence and heat transfer on cones without and with finite angles of attack [7C, 16C, 51C, 65C]. Heat-transfer coefficients in the upstream region could be predicted by a Newtonian flow approximation and by the principle of local similarity [16C]. Heat transfer during transient heating of a hemisphere at Mach number 2 was found to be independent of the wall-to-free-stream temperature ratio in the laminar boundary-layer region and to decrease by 20–40 per cent with increasing wall-to-free-stream temperature ratio in the turbulent boundary layer [23C]. Careful measurements of the temperature and velocity profiles in a turbulent boundary layer on a flat plate with heat-transfer at a Mach number 5·2 established the validity of Reynolds analogy [63C]. The effect of roughness was investigated on two-dimensional and swept wings in supersonic flow [12C, 18C, 25C, 58C, 60C]. The study included a consideration of transverse contamination behind single roughness elements [18C] and established that along the stagnation line of a 60° swept wing the heat-transfer coefficient was by 40 per cent less than for zero degree sweep. No difference was found over the rest of the surface. A cylinder mounted normally on a flat plate or on a streamlined object and exposed to flow normal to its axis, experiences heat-transfer coefficients which on the stagnation line and close to the flat plate are up to three times as large as values on the cylinder alone [9C, 43C]. On the flat plate downstream of the cylinder, the heat-transfer coefficients were up to ten times larger than the values on the plate without the cylinder. An experimental study of the effects of a non-uniform wall temperature on heat transfer in laminar and turbulent axisymmetric flow along a cylinder resulted in heat-transfer coefficients which agreed somewhat better with a theory proposed by Seban than with one by Rubesin [22C]. In the proximity of the transition region, the boundary layer was found to have the tendency to become asymmetrical. Extensive measurements of the temperature field within the boundary-layer region are reported for flow over spheres [4C]. The influence of upstream turbulence was found to increase local Nusselt numbers when negative pressure gradients existed along the surface [32C, 33C]. No effect was found for a flat plate with flow at constant pressure. The increase of heat transfer was largest at low turbulence intensities. Formulas have been developed from experiments for heat transfer between a jet and a plate held normal to the flow [54C].

FLOW WITH SEPARATED REGIONS

Heat transfer in separated regions has found special attention in the recent past. A number of publications appeared during the last year which attempt to study details of the flow and heat-transfer process. Extended measurements on local heat transfer to the wall of a recessed notch investigated the influence of Mach number, geometry and boundary-layer thickness of the arriving flow. It was found that heat transfer increases strongly when a periodical filling and emptying of the fluid in the notch occurs and a theory is developed which analyses this process [4D]. Heat transfer in the reattachment zone of a separated laminar boundary layer is treated analytically, assuming that the fluid in this region approaches the wall normally [5D]. The results agree well with measurements. Free flight observation of a separated turbulent boundary layer at Mach number 8·5 ahead of a forward facing step on the cylindrical portion of a hemisphere-cone-cylinder showed that heat transfer in the separated region decreased in agreement with previous investigations [14D]. The transition Reynolds number of separated flow at supersonic velocities was found to be between 6×10^4 and 4×10^5 based on the length of separation. The critical Reynolds number decreased with wall cooling. Cavity resonance caused a large decrease of the critical Reynolds number [13D]. Two papers [1D, 7D] present the results of an investigation of separated flow with high stagnation temperature (2000–4000°K). That separation of the flow may also occur on upstream facing parts of an object, is demonstrated by measurements of the pressure distribution and of local heat transfer for flow over concave hemispheres [8D]. New measurements extended our knowledge of heat transfer from water to a sphere or transverse cylinder to high Reynolds numbers [17D, 19D]. The following relation

$$j = 0{\cdot}692\ Re^{-0{\cdot}486} \text{ for } 500 < Re < 5000$$
$$(j, \text{ Colburn factor})$$

was found to describe heat- and mass-transfer coefficients well for twenty shapes of blunt objects when the characteristic length in the Reynolds number is the ratio of surface area to maximum perimeter normal to the flow direction [16D]. Heat-transfer characteristics have been reported for tube bundles with fins or of novel shapes [2D, 3D, 15D].

Several investigations deal with packed beds. The stagnant conductivity including radiation is calculated for spherical particles assuming no motion for the fluid filling the cavities [11D]. Heat transfer connected with forced flow through a packed bed is measured by a mass-transfer analogy [20D, 22D]. One of the spherical particles in the bed is coated with a material which transfers mass to the fluid. Heat and mass transfer has been measured for particles of various shapes [9D]. The effective thermal conductivity in a packed bed with particles of glass and metal was found to increase faster with Reynolds number when the heat flow was directed opposite to the air flow than for the case that both flows move at right angle [21D]. Apparent heat conductivities were reported for Reynolds numbers between 10 and 10^4 [12D]. A study correlated the data of fourteen investigators for heat transfer in fluidized beds. It was pointed out that further studies are required to definitely establish the influence of Prandtl number, particle shape, and void fraction [6D]. Sound and vibration influence heat transfer only when their intensities are beyond certain threshold values [10D, 18D].

TRANSFER MECHANISMS

The study of the detailed mechanism of transition to turbulence and the turbulence characteristics has continued during the past year. An analysis showed that velocity profiles in the early process of growing instability can have two inflection points, and it is assumed that this situation may lead to a secondary instability and to transition [3E]. A Schlieren system with spark illumination and a cylindrical lens camera was developed to study the transition process in an air stream at Mach number 1·96 [13E]. The cylindrical lens presents the direction normal to the surface in a large scale, and two consecutive sparks give pictures 28·5 μs apart. It was found that turbulent spots erupt simultaneously over an area comparable in size to the wavelength of a Tolmien–Schlichting wave. An analysis of flow with equilibrium between supply and dissipation of turbulent energy lead to detailed information on the transfer process [15E]. Mixing-length functions based on Kármán's similarity law were used to study the mixing process in a turbulent vortex system [11E]. The constant k in the expression for the turbulent diffusivity was found from experiments to be 0·04–0·08 in contrast to the value 0·4 in turbulent tube flow. Statistical turbulence analysis was extended by the inclusion of three-point and three-time correlations [8E, 6E]. It was found in agreement with experiments that temperature fluctuations decay slower than velocity fluctuations especially in high Prandtl number fluids. A novel method was developed to measure two-point correlations and spectral density in a turbulent jet of smoky air by measurement of smoke-scattered light [12E]. The measurements agree well with published hot wire investigations. The energy spectrum of turbulent incompressible flow has been investigated [10E]. Experiments also indicated that the flow in the core of fully developed pipe flow was nearly isotropic and homogeneous [2E]. Resultant relations between turbulent parameters and mass-transfer parameters agreed well with a theory by G. I. Taylor. Preston's method to measure the wall shear by a total head tube touching the surface was applied through Reynolds analogy to determine local heat transfer in a fluid flow without and with pressure gradients [7E]. Turbulence intensity, temperature and concentration of admixtures in a turbulent wake behind a plate normal to the flow were measured by hot wire, thermocouples, and sampling [1E]. No similarity existed between the temperature and concentration field near the plate. The problem to measure the average velocity and temperature in turbulent pipe flow by measurement at one point only, is discussed in [14E]. Single roughness elements on a surface create with increasing Reynolds number at first vortex filaments, and later transition to transverse contamination [9E] (see Fig. 1). The appropriate roughness Reynolds number is based on stream velocity and characteristic dimension of the roughness [4E]. Atmospheric diffusion of sulfur dioxide gas was predicted from eddy diffusivity values measured for vertical transfer of heat [16E]. Heat transfer between solids and liquid helium II was investigated [5E].

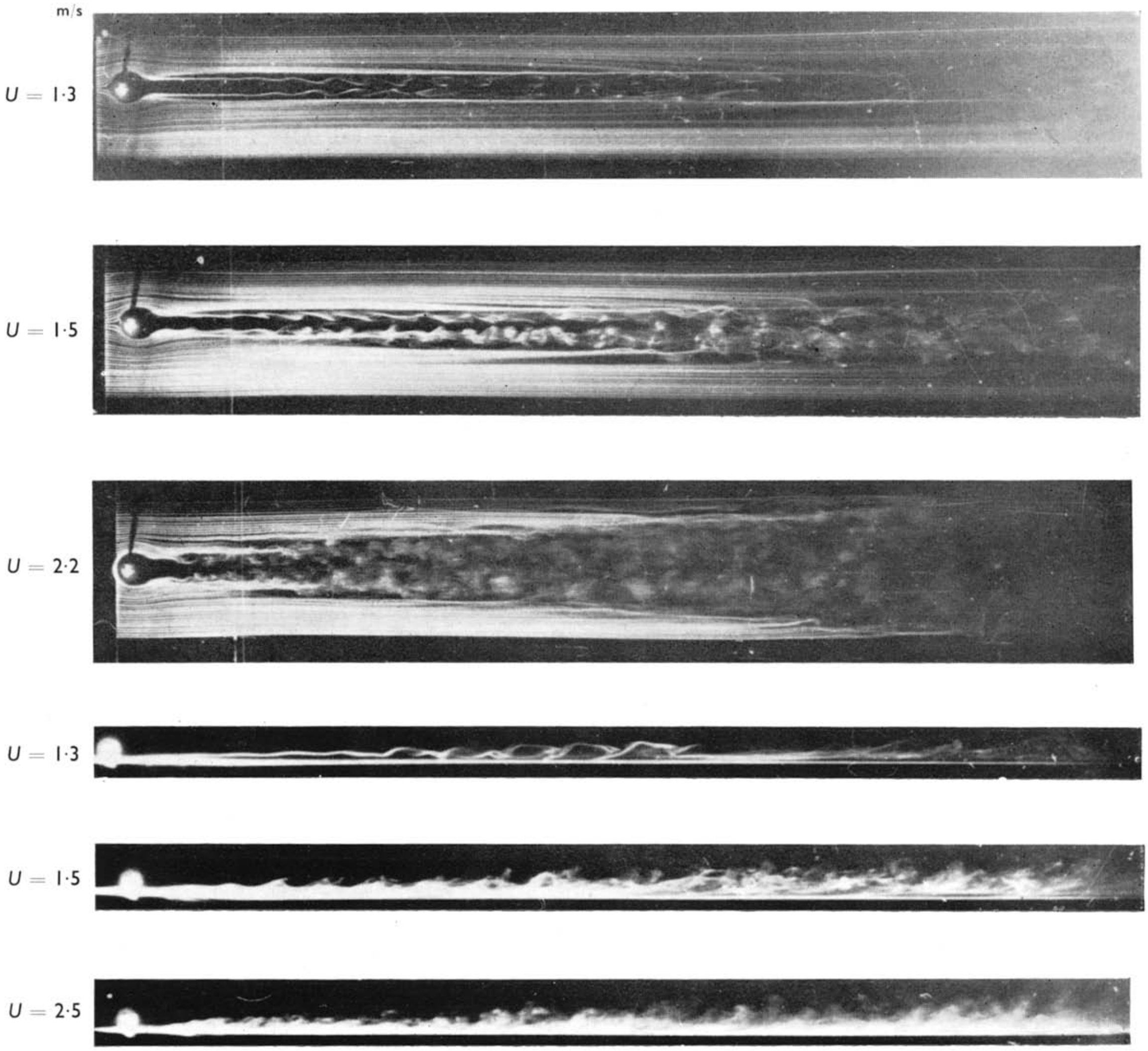
NATURAL CONVECTION

Considerable interest continues in laminar, natural-convection boundary-layer flows. The thermal boundary conditions which permit similar-type boundary-layer solutions for the vertical plate were examined [18F] under conditions of viscous dissipation, suction and injection, and transverse magnetic field. Shapes of two-dimensional and axisymmetric bodies with closed lower ends were derived [2F] for which there is a similarity boundary-layer flow.

The mass flux carried in a heated laminar plume (jet) which rises above a heated cylinder immersed in a viscous oil was calculated [30F] by a boundary-layer analysis. Non-Newtonian flow and heat transfer in a high-Prandtl-number fluid on a vertical surface was analysed [1F] under the assumption that the shear stress is proportional to a power of the velocity gradient. A film theory has been employed [27F] to derive approximate Nusselt numbers for natural convection about bodies of various shapes. Measurements [28F] of boundary-layer temperature and velocity distributions about a horizontal cylinder immersed in water fell somewhat below the predictions of analysis. The deviations from quasi-steady heat-transfer conditions due either to a prescribed time-dependent body force or surface temperature have been found [4F]. A method for calculating the time-variations of the (spacial) average surface temperature has been presented [10F] for solid vertical cylinders subject to internal heating and external natural convection.

Analytical and experimental studies have been carried out for combined natural and forced convection. The first-order effects of buoyancy on forced-convection gas flows over a horizontal flat plate were found [20F] to depend on the ratio $Gr/Re^{5/2}$. Experimentally determined laminar heat-transfer data for air flowing in a horizontal tube were correlated [13F, 14F] by a vector superposition of the separate forced and natural convection heat-transfer relationships. Buoyancy effects were not important under turbulent conditions [14F]. Measurements have been made for water [19F] in horizontal tubes in the transition regime between laminar and turbulent flow. The data are correlated by a semi-empirical equation. For flow in a vertical tube, dye filaments have been utilized [26F] to study the influence of natural convection on laminar–turbulent transition. The transition process is found to be quite different depending upon whether the forced and natural convection aids or opposes. An approximate solution has been carried out for the entrance region of a vertical tube including buoyancy forces and variable viscosity [25F]. The approach is similar to the Kármán–Pohlhausen method. A corresponding (constant viscosity) study has been made for the annular gap between two vertical cylinders [21F]. A novel feature of this analysis is that Bessel functions were used in the expressions for the velocity and temperature profiles. The theory for fully developed combined natural and forced convection in a vertical pipe has been extended to include simultaneous mass and heat transfer [11F]. The limits of the interaction between natural and forced convection mass transfer were found [9F] from experiments involving water flow over benzoic-acid spheres.

Simultaneous heat and mass transfer on a vertical plate has been analysed [33F] by the Kármán–Pohlhausen method. The cases of equal-molal counter-diffusion, isothermal wall and adiabatic wall were examined in detail. Dimensionless heat-transfer results derived [31F] for uniform blowing or suction through a porous, isothermal vertical plate differ little from those for similarity blowing or suction ($v_w \sim x^{-\frac{1}{4}}$). Time-dependent suction on an infinite vertical plate having time-dependent thermal boundary conditions has yielded a closed-form natural



Fɪɢ. 1. Top and side views of the vortex pattern behind a single roughness element as a function of velocity [9E].

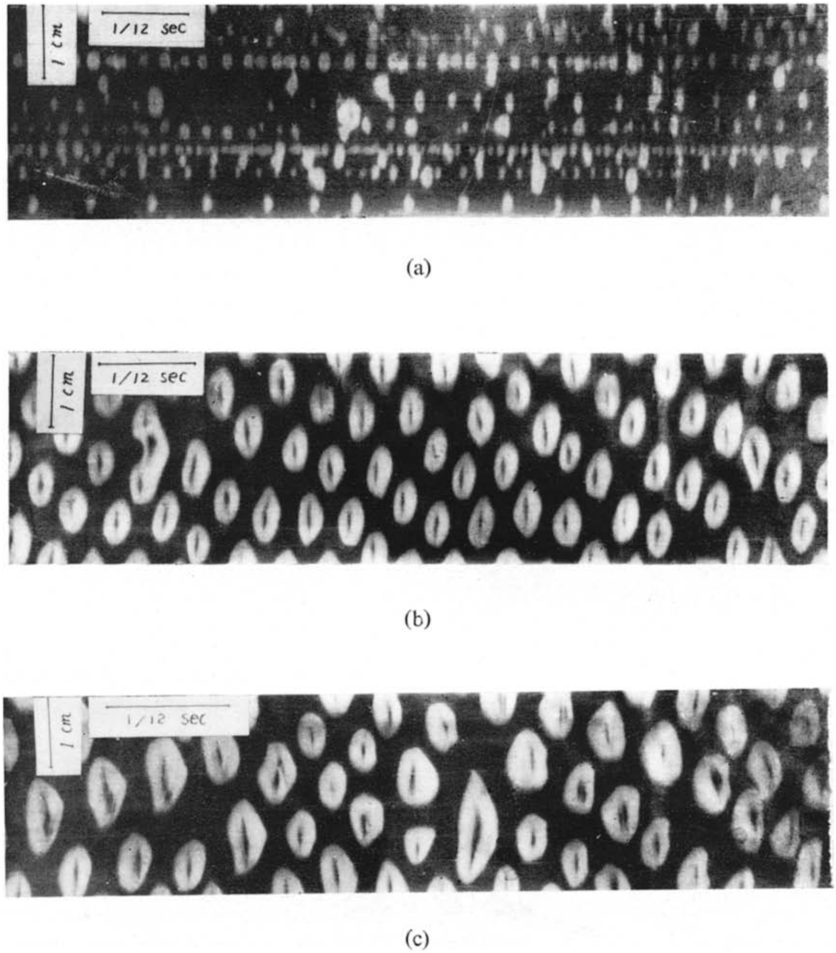


FIG. 2. Photographs of bubbles leaving the heating surface in pool boiling of water at atmospheric pressure. The photographs were taken on a rotating drum with a vertical axis, viewing through a horizontal slit, a plane just above the heating surface. The time increases from left to right. (q = heat flux.) (Reference 28J).

(a) Nucleate boiling region
$q = 1{\cdot}25 \times 10^5$ kcal/m^2 h
(b) Film boiling region
$q = 3{\cdot}36 \times 10^5$ kcal/m^2 h
(c) Film boiling region
$q = 4{\cdot}74 \times 10^5$ kcal/m^2 h.

convection solution [23F]. Natural convection mass-transfer rates for solid, organic acid spheres immersed in solutes were measured [8F] in the Schmidt number range from 410 to 12 000. The effect of vertical vibrations on horizontal cylinders subliming to air was an increase of up to 660 per cent over the steady free-convection mass-transfer coefficients [17F].

The temperature field in an air layer enclosed between two vertical isothermal plates has been investigated [6F] with a Zehnder–Mach interferometer. Various flow regimes were delineated as a function of Grashof number and height-to-thickness ratio. The effects of tube length–diameter ratio and inclination angle on the temperature distribution along a uniformly heated thermosyphon were studied experimentally [16F] for both water and mercury. Tilting the tube gave rise to better heat-transfer performance. A horizontal cylinder filled with water was heated on part of its surface and cooled on the other part [29F], and the effect of changing the relative location of the heated and cooled regions (with respect to the direction of gravity) was investigated.

The stability of various free convection flows continues to attract analytical interest. The classical Benard problem wherein a flat layer of fluid is heated from below has been generalized [35F] to include non-uniform heating at the base surface. The flow pattern for Rayleigh numbers well-above the critical instability value has been solved for [15F]. Several papers [3F, 34F, 32F] treat problems in which density differences interact with body forces set up by rotation. The latter of these also includes magnetic field effects.

The magnetohydrodynamic free-convection boundary-layer flow on a vertical plate is shown [24F] to yield similarity solutions when the magnetic induction varies as $B \sim x^{-n}$, and the wall temperature varies as $T_w - T_\infty \sim x^{(1-4n)}$. Fully developed, combined forced and free convection in a vertical parallel-plate channel has also been analysed [22F] for a magnetic field normal to the plates. In a companion problem [22F], the motion in the cross section of a horizontal cylinder filled with a conducting, current-carrying fluid is solved. The effects of a transverse magnetic field on the free-convection motion of a liquid metal in a vertical tube are shown to be appreciable [5F].

A heated horizontal cylinder was subjected to a horizontal transverse sound field [7F]. Above a certain critical sound pressure, it was found that a significant increase in the heat-transfer coefficient above its free convection value can occur. A qualitative explanation for this phenomenon has been offered [12F].

CONVECTION FROM ROTATING SURFACES

Laminar heat-transfer results for a non-isothermal rotating disk have been obtained [2G] from numerical solutions of the boundary-layer energy equation for Prandtl numbers between 0·1 and 10. The surface temperature variations considered in the analysis are described by $T_w - T_\infty \sim r^n$ (r = radial distance along disk surface). This same problem was alternatively attacked [1G] by introducing an approximate representation for the velocity profile into the energy equation. The results are believed to be accurate to within 10 per cent over the Prandtl number range 0·3 to 6. By a simple modification of the final equations, it has been shown [4G, 5G] that laminar heat transfer results for the rotating disk can be applied to the rotating cone, and this is valid whether or not there is mass transfer at the disk surface. Limits of the laminar–turbulent transition regime for flow about a horizontal, heated, rotating cylinder have been proposed [3G] on the basis of semi-quantitative arguments.

COMBINED HEAT AND MASS TRANSFER

Film cooling, where the coolant gas is injected into the boundary layer at discrete locations has been studied by a number of investigators. An approximate method for the estimation of laminar heat transfer to blunt bodies with gaseous film cooling is reported in [27H]. Attention is focused on the parameters which are important for the design of an attractive heat protection system. Turbulent boundary layers with tangential injection have received considerable attention. A pair of companion papers [21H, 22H] presents experimental values for the cooling effectiveness and heat-transfer coefficients when the slot size is varied as well as investigating the effect of initial boundary-layer thickness on the above variables. Another paper [10H] also presents similar information on effectiveness and heat-transfer coefficients as well as measured velocity distributions in the boundary layer and plate temperature distributions. A final paper in this series [5H] reports experimental data on the cooling effectiveness when from one to ten slots are used.

The influence of fluid injection on the downstream boundary-layer characteristics has received attention. Such an experimental study has been reported [3H] in connection with the injection of air and helium in the up-stream portion of a two-dimensional supersonic nozzle. A similar investigation [16H] studied the case of injection at a blunt body stagnation point in hypersonic laminar flow. This same situation was studied analytically in [6H] and experimentally in [29H]. In the latter paper, the effect of induced swirl of the injected gas was also investigated. In a generalized analytical approach [19H] a method for predicting boundary-layer characteristics down-stream of porous regions was studied. The analysis yields integro-differential equations and several numerical examples are presented.

Laminar flow studies over permeable wedges with suction including isothermal and variable wall temperature distributions have been reported [12H]. With such solutions it is possible to predict heat transfer and skin friction over arbitrary geometries. The injection of a foreign gas into a compressible turbulent boundary layer with zero pressure gradient has been investigated [18H]. Comparison with experimental data gave reasonable agreement on the effect of Mach number.

Experiments on the melting of ice in a warm air stream have been reported in [28H]. An approximate theory for predicting the incompressible stagnation ablation rate for ice gave reasonable agreement with the experimental data. A companion paper [13H] yielded essentially the same results. A similar study [23H] using naphthalene cylinders with air flow also reports adequate comparison between theory and experiments.

An extrapolation has been made [7H] of the incompressible turbulent boundary-layer analysis to the case of a turbulent boundary layer with ablation. The effects of dissociation and recombination and surface combustion have been considered. It was found that when the turbulent Lewis and Prandtl numbers are near one, little knowledge of the chemistry inside the boundary layer is required. Such a study has also been made [2H] of the ablation mechanisms in plastics with inorganic reinforcements. Experimental ablation rates for turbulent boundary layers are reported in [1H]. Graphite was the ablating material with a mixture of oxygen and nitrogen as the working gas.

A comparison of three approximate approaches for the calculation of ablation rates has been made [4H] using either an integral method, a quasi-steady assumption or a small surface velocity approximation. Agreement within 15 per cent was obtained for re-entry conditions.

The transition from free to forced convection in the presence of mass transfer on a $\frac{3}{8}$ in diameter sphere has been investigated [9H] for both forced upflow and downflow. The critical Reynolds number was determined at which the free convection effects disappear.

A series of Russian papers have examined the heat- and mass-transfer processes in dispersed media and capillary solids. In [17H] solutions for these processes are presented for a dispersed media during phase changes and for one-dimensional situations. In [11H] an investigation is reported of the experimental temperature and moisture content of a similar media. The difference in the heat-transfer processes when evaporation occurs from a porous capillary than when evaporation occurs from a free surface is discussed in [15H]. Empirical relations establishing the similarity of criteria for heat and mass transfer from the porous capillary surface are determined on the basis of experimental data. A companion paper by the same author [14H] examines these processes when they occur inside of the porous capillary. The final paper in this series [20H] includes a consideration of a compliting chemical reaction occurring simultaneously.

Another series of papers report in detail on mass transfer through laminar boundary layers. In [24H] graphs and tables are presented to assist in the calculation of velocity profiles and in [26H] similar solutions of the energy and diffusion equations are examined. The prediction of mass-transfer rates when equilibrium does not prevail at the phase interface is discussed in [25H] and solutions are presented in [8H] for the energy and diffusion equations in the presence of a pressure gradient under the condition that either the Prandtl or Schmidt number is greater than 0·5.

CHANGE OF PHASE

Research, both analytical and experimental, continues apace in this most important and difficult area of heat transfer.

Boiling

Mendler *et al.* [25J] measured heat-transfer rates to burnout, two-phase pressure drop, and riser density for natural and forced circulation of water at elevated pressures (800–2000 lbf/in^2) under non-boiling, local, and bulk boiling conditions. Further experiments [14J] investigate heating surface temperature variation with heating rate and surface roughness and material for nucleate pool boiling at one atmosphere. In the cryogenic temperature range, Frederking [11J] has measured and correlated the film boiling heat transfer during vaporization of liquid helium and nitrogen. The first study reported of boiling heat transfer between immiscible liquids found neither peak heat flux or a decline in the film coefficient when water, methanol, or ethanol pool boil above heated mercury.

The use of high-speed photography shows the bubble dynamics in nucleate boiling [15J] and suggests a model used to explain heat transfer to a boiling fluid. Photographic study (Fig. 2) of saturated, free convection, stable, film boiling [28J] reveals a marked regularity in the pattern of bubble formation and departures and a dependence on emissivity of the heating surface.

Analytical studies [3J, 4J, 24J] consider film boiling from vertical plates within framework of laminar boundary-layer theory; the latter study also considers horizontal cylinders and the effect of variable specific heat.

Pool boiling in non-standard gravitational fields receives experimental consideration in [35J] by photographs of nucleate boiling in reduced and zero gravity fields and in [26J] by measurement of heat-transfer rates in systems accelerating at 1–21 *g*.

Sublimation in the micron pressure range is observed to occur in instances with appreciable surface temperature depression [23J].

The special heat-transfer problems related to nuclear reactor development continue to receive attention. Houghton [13J] considers the rate of bubble formation at the wall, the rate of growth and diffusion in a turbulent liquid, and devises a model able to predict the void fraction distribution and "burnout" in terms of bubble slip velocity. Another model proposed by Isbin *et al.* [16J] seeks to correlate two-phase (steam, water) burnout heat-transfer fluxes for spray-annular flow in round tubes and rectangular channels. In swirling flow, critical heat fluxes two and a half times that for straight flow are reported [38J].

Heat transfer needs suggested by current engineering concerns prompted the study of the film coefficient for boiling from an absorbent wick material [1J], two-phase concurrent flow in packed beds [21J], the consideration of spray column heat transfer in a distillation system [41J], and multiple-effect, rotating evaporation system for saline water conversion [7J].

Condensation

Photographs of the condensation of binary vapors of miscible liquids [27J] reveal irregular ripples and streaks of non-filmwise condensation.

Konsetov [20J] considers heat transfer during film condensation of steam in horizontal tubes, reporting useful overall results, but because of customary scatter no conclusive proof of theory is possible. Laminar film condensation is examined analytically by boundary-layer analysis considering such effects as superheated vapor and non-condensable gases [32J] and interfacial shear due to induced vapor motion [19J]. Koh [18J] presents an integral treatment of this problem reducing the differential to algebraic equations. Chen, in a two-part study [5J, 6J] of the same problem, examines, analytically, laminar film condensation for the vertical flat plate and single and multiple horizontal tubes. Condensation on a rotating cone [33J] is viewed by the authors as supplanting the absent gravity force in space vehicles.

Novoselov [30J] considers the behavior of a spherical drop in slow and fast descent in the presence of surface condensation and evaporation.

Condensation in rapidly moving gas streams is examined considering the effect of droplet surface tension [29J] and also the possibility of entering a thermodynamic region of absolute instability [17J]. In this same area, Steltz [34J] considers choking flow of a compressible fluid across the phase boundary for frozen and shifting equilibrium.

Two-phase flow

The flow of liquid films and gas in vertical pipes was examined for the case of stagnant gas and the more practical case of counter gas flow by Feind [10J]. The influence of Reynolds and Prandtl number variations on the heat-transfer coefficient for thin layers is reported by Wilke [40J]. Sachs and Long [31J] report that for vertical upward flow of a saturated liquid through a heated annulus, an annulus of vapor surrounds the thin liquid layer on the upper regions of the heater surface. Here no nucleate boiling occurs and the view that heat transfer in this stratified zone is purely convective is substantiated by results. Steam–water mixtures of high quality were studied experimentally in electrically heated, horizontal, rectangular, ducts [9J], the results agreeing with those of other studies when round tubes were used.

For two-phase dispersed flow, [36J] presents the equation of motion and energy balance on such systems and [2J] the experimental heat-transfer measurements for steam–water mixtures in an annulus.

Using a simple momentum model, Levy [22J] predicts steam slip and reports good correlation of pressure drop measurements in horizontal and vertical test sections with and without heat addition. Zuber [42J] reports success of a variable density, single fluid model in correlating two-phase, counter-gravity flow of water–steam and water–air systems.

Low temperature, two-phase boiling measurements on liquid oxygen and liquid nitrogen in circular tubes [37J] find film coefficients markedly different from those based on pool boiling data, emphasizing the importance of two-phase effects.

Mathematical analysis of the three modes of oscillation of a simple, natural convection two-phase system is compared with results from a small scale loop model [39J].

Finally, a useful review by Courtney [8J] of advances in condensation and evaporation cites the limited information available in the area of propulsion and high-speed flow but reveals the broad sweep of the subject (114 references).

RADIATION

Radiation exchange problems in space continue to be of interest to a number of investigators. The radiation incident to a plate located various distances above the earth has been calculated [7K]. A similar study [25K] investigates the temperature distributions in two disks subjected to solar radiation. The influences of disk radiation properties, thermal conductivity and spacing have been examined to explore the possibility of using a movable shield as a temperature control device for a space vehicle. The results from another paper [9K] indicate that significant errors can occur if the angular dependence of radiation characteristics is neglected in making radiation equilibrium calculations for objects in space.

Calculations relating to radiating fins have been further refined. A parametric solution has been presented [24K] for a rectangular radiating fin from which the optimum dimensions for minimum weight have been determined. A radiating fin with exponential sides has been investigated [14K] and the optimum geometry specified. The above calculations relate to single fins and do not consider the possibility of multi-fin arrangements with mutual irradiation between fins. Such a study has been presented [30K] where the temperature distribution, local and overall heat loss and fin effectiveness have been determined for a tube with external longitudinal fins spaced at 45, 60, 90 or 120°. The influence of radiation interaction between fins has been considered and the conditions for minimum weight have been specified.

A number of papers have presented measured radiation properties for both gases and solids. In [28K] the spectral emissivity of anodized aluminium is reported for various values of surface roughness and over a temperature range from 200 to 540°C. The results indicate that the emissivity varies strongly with surface roughness and oxidation but only slightly with temperature. In another investigation relating the surface roughness [2K] the spectral reflectance at normal incidence has been studied analytically and experimentally. It is shown that spectral reflectance measurements may be used as a simple and sensitive method for the determination of surface finish.

The reflectivity of silver chloride in the wavelength range 0·215–0·375 μ has been reported [18K]. The measurements were obtained at both room and liquid nitrogen temperatures. Another study [17K] presents data useful in the design of radiometers. The spectral reflectivity of seven gold mirrors has been measured over wavelengths from 8·5 to 84 μ.

The spectral emissivities of CO_2–H_2O mixtures have been reported [35K]. The measurements were obtained at a wavelength of 2·7 μ and the mixture concentrations correspond to the stoichiometric concentrations of CO_2 and H_2O in a propane–air flame. Similar measurements have been obtained for pure CO_2 at a wavelength of 4·3 μ [36K]. A discussion is presented relating the measured spectral emissivites to molecular energy distributions, theoretically calculated emissivities and flame radiation.

The problem of heat transfer in transparent solids has received attention from several investigators. In [15K], spectral transmissivities of glass at high temperature are presented and a discussion is given of the application of these data to calculation procedures In [12K] a review is presented of the current knowledge of radiant heat-transfer phenomena in glass.

Several configuration factors for radiant energy exchange have been reported. One investigation [6K] was concerned with shape factors between axisymmetric sections of cylinders, cones, and hemispheres and their bases. In [16K] an approximate formula for the solid angle subtended at a point by a right circular cylinder is derived and the error involved in the approximation is evaluated.

The theory underlying the measurements of total hemispherical emissivity has been reviewed in [26K]. An apparatus is described which is suitable for such measurements and data obtained on Inconel, stainless steel 303, and titanium alloy, RS–120, in the temperature range 600–2000°F are reported. Both normal and directional total emissivities were measured. An integrating sphere for determining spectral reflectivities and transmissivities as a function of angle of incidence in the wavelength range 0·33–2·5 μ has been described [11K]. The apparatus can be used for surfaces which are neither completely specular nor completely diffuse in their reflecting properties. An interesting paper [10K] examines the common assumption made in many measurements of total emissivity that the sample surface is gray. It is shown that when the sample and environment temperatures are near the same value the error may become significant.

In calculating the heat transfer to a high-speed object entering an atmosphere, most analyses have concerned themselves with the convective phenomena involved. A related question which arises is the effect of radiative transport of energy in these high-speed boundary layers. The influence of this radiative transport to stagnation point heat transfer has been discussed in a number of papers [5K, 13K, 20K, 21K, 22K 23K]. An interesting aspect of these calculations concerns the fact that a rigorous solution considering the coupling of the radiation and convection modes is particularly formidable. Thus the approximations which are made in order to make the problem tractable are open to a great deal of discussion. One paper [37K] has examined the coupled radiation and convection problem using a simple type of flow, a couette flow. If the convective process takes place in the presence of mass transfer in the boundary layer, the complications increase even more. One paper [34K] investigates this situation for the case where the foreign gas is transparent to thermal radiation and a second paper [19K] considers the case where the foreign gas absorbs thermal radiation.

A number of papers are concerned with various aspects of enclosure theory. The effect of assuming that each of the two parallel plates are gray in calculating the radiant exchange between them is examined in [4K]. A calculation was made using the actual spectral radiation properties of tungsten and comparisons made with the gray-body calculations. The error in this particular case can be as large as 25 per cent. Another assumption often made in enclosure theory is that the radiation incident upon a surface is uniformly distributed. This assumption has been examined in a pair of papers for parallel circular disks [31K] and for two plates either sharing a common edge or parallel [32K].

A special enclosure theory has been developed for the situation where not all of the surfaces involved are diffusely reflecting [8K]. The systems considered were those having two specularly reflecting surfaces and an unrestricted number of black surfaces. Another paper [3K] examines the general problem of normal enclosure theory and presents a calculation procedure which is then compared with more exact and less exact schemes.

An unusual radiation situation has been examined in [27K]. The distribution of radiation intensity is calculated in the inside of an infinite hollow circular cylinder where the temperature varies arbitrarily in any cross section but is invariant along the length. A similar study [1K] answers the question, "Of the total radiant flux produced in a right circular cylindrical cell containing a uniformly distributed isotropic source of radiant energy, what fraction emanates from the end of the cylinder?" The calculation is made for cells with both perfectly reflecting and perfectly absorbing surfaces.

The radiation heat transfer in a spherical enclosure containing a radiation-absorbing and heat-generating gas has been analysed in [33K]. The gas is assumed gray, molecular conduction is neglected, and the bounding walls are specified to be black and isothermal. The gas temperature is calculated and an approximate solution is presented and compared with the exact integral solution. The radiant heat transfer from a luminous flame has been investigated theoretically and experimentally in [29K]. The relation between the emissivity of the luminous flame and the quantity of carbon products is reported.

Cavity sources of radiant energy are often used as radiation standards in experimental work. A review of the theories of cavity-type radiation sources which have properties approaching those of black bodies is presented n [38K]. The approximations involved in each theory are noted. Relationships for several cavity shapes are derived for calculating the effective emissivity in terms of cavity dimensions, radiation properties of walls lining the cavity and aperture size.

LIQUID METALS

The suggestion that longitudinal conduction is responsible for disparities between analytical and experimental heat-transfer results for low-Peclet-number tube flows has received strong support. In an experiment [8L] involving mercury flowing in a horizontal tube, longitudinal-conduction corrections were made in evaluating the bulk temperature, and the resulting Nusselt numbers were within 9 per cent of the theoretical laminar prediction of $48/11 = 4{\cdot}36$. Data for the transition regime are also reported. An analysis [9L] demonstrated that longitudinal conduction could strongly effect the laminar Nusselt number predictions when the Peclet number is below 10.

Experiments [1L] on liquid sodium flowing transversely to a single heated cylinder indicated that the highest heat transfer is at the forward stagnation point and the lowest at the rear stagnation point. The Peclet number range was 25–125. Natural convection heat-transfer measurements have been carried out [7L] for liquid sodium cooled by a horizontal plate facing downward. The fluid flow pattern has been inferred from temperature measurements. Entrance region and fully developed mass-transfer data have been obtained [5L] for liquid lithium flowing in a circular tube for the Reynolds number range 5500–22 000. The fully developed data are correlated by a j-factor equation.

An analysis for turbulent tube flow which utilizes a recently proposed mixing-length hypothesis has confirmed [2L] earlier findings that results for the uniform heat flux and uniform wall temperature boundary conditions are not the same for liquid metals. Predictions of turbulent liquid-metal heat transfer for flow longitudinal to rods in regular array have been made [4L] using the method of Lyon. For a given ratio of pitch to diameter, the Nusselt number results are a function of Peclet number alone. For laminar boundary-layer flow under the condition of asymptotically small Prandtl number, it is shown [3L] that the energy equation reduces to a transient heat conduction equation with variable properties.

Information available has been summarized [6L] on the effects of free convection on the liquid-metal heat transfer from a vertical sealed ligament within which there is an internal heat generation.

LOW-DENSITY HEAT TRANSFER

A concern with heat transfer at low pressure and supersonic velocities appears to dominate the research activity in this sector, reflecting undoubtedly, space flight requirements.

Drag experiments with spheres at low density and supersonic speeds [9M] cover a free stream Reynolds number range of 50–1000 and Knudsen number range 0·006–0·206, clarifying and extending information in this area.

For a flat plate in hypersonic, continuum flow [5M] reports the finding of slip over a limited region (of the order of five molecular collisions) near the leading edge. Other experiments [6M] have found stagnation point heat-transfer rates higher than those predicted by incompressible boundary-layer theory for hypersonic, low-density flow.

Theoretical study of a moderately rarefied gas [4M] follows Prandtl's boundary-layer theory but yields results differing from the ordinary equations by the presence of supplementary terms containing higher derivatives of velocity and temperature. Dumitrescu [2M] considers the temperature field and flow of heat within bodies (moving at high speed through rarefied gases) caused by the difference in energy flux at forward and rear faces of the body, demonstrating that assumptions of an isothermal surface as made in other studies holds only for infinite conductivity. The general problem of heat exchange between a surface and a gas is considered for slip flow of rarefied gas and for dense gas, resulting in analytical relations, general and numerical, describing the heat flow [8M].

The static problem of heat flow through a rarefied gas layer between two parallel plates is considered and the temperature distribution determined by adopting different distribution functions for approaching and reflecting molecules in order to satisfy the boundary conditions at the surfaces [3M].

Abarbanel [1M] considers the interesting problem of the effect of thermal radiation on equilibrium temperature in free molecule flow. By appropriately rendering the temperature dimensionless, solutions are found in terms of a similarity parameter enabling body temperature to be specified in terms of flight conditions, body geometry, and surface properties for high speed flow.

Those entering this particular area of research would do well to capitalize on the experience of Patterson, aspects of which are reviewed [7M] in considering the interpretation of probe pressures and associated problems at very low densities.

MEASUREMENT TECHNIQUES

A new technique for the measurement of thermal radiation has been proposed [9N]. The instrument is based upon the relationship between temperature and the dielectric constant of materials and promises greater sensitivity than conventional detectors because of inherently low noise levels. A difficult problem in the detection of thermal radiation is found in measurements taken inside a rocket or jet engine. An instrument has been described [21N] which can measure radiation fluxes of the order of 1 cal/s ft^2 under the severe mechanical and pneumatic forces found in jet engine combustion chambers. A third paper in this area [13N] reports the results of experiments on the influence of gas on the response time in vacuum thermopiles. Air, argon, helium, and neon were studied and it was found that the pressure always had to be greater than 100 μ before any effect was noticeable.

Several transducers for the measurement of surface heat flow rates have been described. Using thin film resistance thermometers on slabs of alumina or pyrex, gages have been developed [3N] to measure heat fluxes between one and 10 Btu/s ft^2. Another transducer [6N] uses a plated surface thermocouple to make similar measurements.

Two techniques, alternate to the use of guarded hot plates for the measurement of thermal conductivities of insulating solids, have been reported. The first [19N] is an unguarded instrument which uses teledeltes paper as the energy generating plate and aluminum sheets for the cold plates. The entire assembly is held together with rubber bands and appears to be particularly useful for rapid measurements of moderate accuracy. The second paper [8N] describes a transient technique which is both rapid and accurate giving results which are within 3 per cent of accepted values.

An often-used infra-red energy source in spectroscopic radiation measurements is a globar unit. A useful investigation [14N] reports the spectral emissivity characteristics of globar sources. Another study [17N] describes a slit-aperture black body source which operates up to 2000°C and which may be used for radiometric investigations of flames and quantitative emission spectroscopy.

Two techniques for the measurement of fluid viscosity are discussed in a pair of papers. An investigation of the end effects in falling-sphere viscometers are studied in [12N]. Corrections are given which take into account both the bottom solid surface and the upper free surface of the viscometer. The second paper [10N] gives a complete description of a narrow gapped co-axial cylinder viscometer which is particularly designed for application to non-Newtonian fluids.

Optical techniques of fluid temperature measurements have the advantages of non-disturbance of the fluid flow field and the simultaneous determination of the temperature in a number of locations. A method making interferometric temperature measurements in flat laminar flames is described in [16N]. With a flame of 4 mm thickness, sixty measuring points were obtained. A Schlieren technique has been applied [4N] to the measurement of density in a laminar boundary layer. Changes in density of 0·006 per cent of atmospheric density were detected. Another optical technique is the use, of flow visualization to study flow fields. The tellurium dye method has been applied to the measurement of velocity profiles in a laminar free convection boundary layer in [5N].

Thermocouple errors when the thermocouple is located in a solid and heat flows down the leads is examined in [2N]. The two cases considered are when the leads are radiating and when they are located in a stationary gas having a different temperature than the solid.

A number of papers have reported on techniques for measuring temperatures especially at either high or low temperature ranges. The fact that in laminar tube flow the pressure drop is proportional to the product of temperature and viscosity, has been utilized for gas temperature measurements in [11N]. Using known viscosity data and measured pressure drops, gas temperature measurements were made up to 1788°K. A description has been given [22N] of an indium resistance thermometer suitable for use in cryostats where working space is limited. The ice point resistance of this instrument changed by less than five parts in 30 000 after repeated coolings to 14°K. For high temperatures the design and performance of a platinum resistance thermometer is discussed in [1N]. The coil resistance at 0°C is 1·4 Ω permitting measurements to an accuracy of 0·002°C. The thermometer has been found to be stable up to 1063°C.

The method of constructing small "needle point" thermocouples of low mass is reported in [20N] where an electroplating technique has been utilized. By using calibrated photographic emulsions, temperature maps have been photographed [18N] in the temperature range 1400–3600°F.

Thermocouples for use above 2000°C in carbon atmospheres are described in [15N]. E.M.F. versus temperature and stability of calibration are reported for a number of thermocouple combinations. In the same area of high gas temperature measurements, a cooled-tube pyrometer is discussed in [7N]. Experimental data were obtained in a subsonic gas stream over a pressure range of $\frac{2}{3}$–$1\frac{1}{2}$ atmospheres and a temperature range of 1600–4400°R.

HEAT-TRANSFER APPLICATIONS

Heat exchangers

The double pipe heat exchanger in which a liquid is heated in a tube by a condensing vapor has been extensively studied [8P, 9P]. Design equations are presented which account for property variations in the liquid. Another investigation on the same type of heat exchanger

[3P] reports the results of a simple experiment which examined the effects of vibrations of the air stream in the inner tube.

The effects of tube bundle to shell clearance, mean oil and water temperatures, and oil flow rates on the shell side heat-transfer coefficient and pressure loss of a shell and tube exchanger are presented in [10P]. The flow was laminar and both unbaffled and cross-baffled exchangers were investigated. In [2P], local shell side heat transfer and friction losses were measured on a model tubular heat exchanger. The exchanger which was 6 inches in diameter and 45 in long contained four tubes in a triangular arrangement passing through orifice baffles.

A method for obtaining the fluid and metal temperature distribution in a plate-fin type heat exchanger is presented in [12P]. The method is illustrated by considering regenerators of cross flow and cross counter-flow types for small gas turbines. It is concluded that the latter are more compact and will have smaller thermal stresses. In the same area of interest, a simple theory applicable to gas turbine regenerators is discussed in [6P].

A pair of papers examines extended surfaces in great detail. In [4P], a general discussion of the various types of extended surfaces presently available is presented and their design characteristics are investigated. In [5P], the factors affecting fin efficiency are considered and some typical designs are illustrated with cost being a factor in the design.

An unusual heat exchanger is described in [7P] in which a fluid to be cooled by air is passed through a bank of tubes around which froth is generated by passage of the air upwards through a tray containing water and fitted with a perforated plate. The significance and use of this method of increasing the air side heat-transfer coefficient is discussed and illustrated by several sample designs giving the dimensions of froth exchangers for different air conditions. An experimental investigation of heat transfer to a gas stream containing suspended particles is reported in [11P]. A correlation of the data was obtained and is discussed. The fourth in a series of such papers [13P] investigates the dynamic response of heat exchangers having a sinusoidally time dependent rate of internal heat generation. A resonance phenomena in the amplitude ratio and phase shift is described.

Cooling towers are discussed in large detail in [1P]. Current theories and the resulting equations employed in the calculation and analysis of cooling towers are reviewed and the basic assumptions in these theories are examined.

Aircraft and space vehicles

Various heat protection schemes for lifting and ballistic-type vehicles undertaking satellite and circumlunar missions have been discussed and analysed in several papers [1Q, 2Q, 3Q, 8Q, 12Q, 14Q]. Ablation cooling has found special consideration [12Q], the effect of radiation from the gas cap between the shock wave and the vehicle [1Q] as well as solar radiation and reflection from the earth [14Q] has been included, and control of the absorbed heat by change of shape or attitude of the vehicle during re-entry through the atmosphere has been considered [2Q]. A good survey of the material requirements of supersonic flight vehicles for the air frame and the propulsion components is presented in [8Q]. Weight optimization of heat rejection systems in space-like fin and tube radiators becomes an important consideration [13Q]. A balloon as satellite may be destroyed when the internal pressure determined by thermal conditions and the external stagnation pressure and radiation pressure are not properly balanced [5Q].

The design of rocket combustion chambers and rocket nozzles depends strongly on heat-transfer considerations. Measurements on local heat-transfer rates in rocket nozzles indicate that tube flow correlations do not describe these rates properly [9Q], that, on the other hand, a boundary-layer treatment leads to satisfactory results [6Q]. A change in the injection methods of the liquid fuels into the combustion chamber may cause variations of local heat-transfer rates by a factor of 2 [7Q]. Radiative transport in solid materials of various transparency can be utilized to cool rocket nozzles [4Q]. An analysis of a nuclear rocket nozzle with hydrogen as coolant indicates that regenerative cooling is not sufficient [11Q]. Experimental results and analytical relations for liquid film cooling of a rocket motor have been presented [16Q].

Test runs on the air cooled turbine of a turbojet engine with corrugated insert blades have shown the blade temperature to be 1300°F at a gas inlet temperature of 2500°F, at a coolant to gas ratio of 0·022, and at 260°F coolant inlet temperature [10Q]. The mirrors of solar collectors for use in thermionic power systems in space and automatic aperture positioners have been discussed [15Q].

THERMODYNAMIC AND TRANSPORT PROPERTIES

Theoretical work seeks to establish accurate microscopic models to portray aggregate molecular behavior or to generalize existing data using the corresponding states principle. Experimental measurements stress behavior at extreme conditions of high or low temperature or at the critical state.

Thermodynamic properties

The accuracy of the Morse intermolecular potential for several non-polar gaseous substances is examined [22R] and its predictions of second virial coefficients compared with those of the Lennard–Jones (6–12) and Buckingham (exp.–6). This same potential is used to demonstrate how vibration–rotation term levels may be calculated numerically for a diatomic molecule from an arbitrary potential curve [8R].

Analytical studies at low temperature result in an equation of state for nitrogen accurate to 0·7 per cent [4R] and a p,v,t, nomogram for hydrogen [39R], while a critical survey [30R] and analysis [31R] of the p,v,t, data for water in the critical region leads to a graphical interpolation technique of present experimental data. Three parameter statements of the principle of corresponding states permits accurate p,v,t, generalization of diatomic behavior [6R] and binary mixtures involving a polar substance [38R]. Reviewing the reduced characterizations of binary gas mixtures [5R], a modification of the Kay method is proposed for engineering calculations.

At high temperature, Krudin [23R] proposes a state equation for approximating the thermodynamic functions of a partially ionized gas. For treating gas-dynamic processes in air at high temperature, Lutz [24R] presents a diagram useful to 100 000°K and Hansen [13R] constant entropy properties, based on an approximate model, to 15 000°K.

Heat capacities of solids and liquids at or near normal temperatures may be simply calculated using a model proposed by Brock [2R].

For sulphur dioxide, p,v,t, measurements [19R] are used for calculating properties [20R] from −100 to 480°F, and for pressures up to 4600 lbf/in^2. Also reported are compressibility measurements of carbon dioxide–nitrous oxide mixtures accurate to ±0·10 per cent. For nitrous oxide, p,v, isotherms are reported from −30 to 130°C and from 6 to 315 atm, yielding compressibility factors accurate to 0·2 per cent [7R].

Recent laboratory determinations of carbon-dioxide absorption indicates the presence of this gas in the Venus atmosphere at 15 per cent by volume [21R].

High temperature drop measurements [1000–2500°F] yield heat capacities for the oxides of aluminum and thorium [17R].

Transport properties

The principle of corresponding states for transport properties is demonstrated on theoretical grounds by Helfand and Rice [15R] and applied to the calculation of thermal conductivities of twenty-eight gaseous hydrocarbons with an average deviation of 2·4 per cent [27R]. The thermal conductivities for liquid and gaseous ethylene are correlated on the same basis to within 1·8 per cent on the average and the results used to predict the same property for gaseous aliphatic hydrocarbons and their derivatives with an average accuracy of 1·63 per cent [32R] Liquid and gaseous ammonia thermal conductivity (and viscosity) is also treated on a reduced basis [12R]. For two-phase systems of the packed bed or porous type, attempts are made to determine a suitable model and to relate the system thermal conductivity to the constituent values [41R, 10R, 37R].

A modified Stockmayer potential shows success in predicting the viscosity of moderately polar gases [18R]. In [16R], Hirschfelder *et al.* find the conditions where the viscosity of a binary mixture of dilute gases has a maximum or minimum with respect to variations in composition. Brokaw [3R] has developed useful alignment charts for predicting low-density transport properties for non-polar gases and gas mixtures based on kinetic theory.

At high temperatures the transport equations for plasmas in an intense field [25R] and the transport properties of high temperature are predicted using recently determined interaction potentials in partially dissociated air [1R].

The problem of thermal diffusion in binary gas mixtures is considered in [35R], the thermal diffusion factor predicted by two different theoretical procedures being compared with experimental measurements for binary mixtures.

Experimental thermal conductivities are reported [8R] for the pure gases (H_2, CO, CO_2, O_2, air, N_2, CH_4, C_2H_6, NH_3, and H_2O) and gas mixtures (N_2–CO, NH_3–N_2, CO–CO_2) from 0 to 1200°C using a hot wire cell. The same basic scheme is used in [11R] to measure thermal conductivities of binary and ternary mixtures of N_2, NH_3 and H_2 from 25 to 149°C, and another variation of the method for conductivity measurements of the $N_2O_4 \rightleftharpoons 2\,NO_2$ system from 32 to 90°C [36R]. Carbon dioxide and carbon dioxide air conductivities are obtained through direct Prandtl number measurements (285–450°K) and predicted to 1500°K [29R]. Shock tube measurements of air conductivity to 4600°K [34R] refine earlier work and substantiate the use of predicted values for many engineering uses. Thermal conductivities (and viscosities) for rare gas mixtures (Kr–Ar, Kr–Ne, Kr–He) are reported [40R] for 18°C and found in agreement with predictions based on Lennard–Jones 6–12 potential. Liquid thermal conductivity measurements for toluene, kerosene, and some organic heat-transfer fluids are reported over the temperature range 15–400°C [43R, 44R, 45R]. A flash method for determining thermal diffusivity, conductivity, and heat capacity of solids is reported for the first time [33R], with results for Cu, Ag, Fe, Ni, Al, Sn, Zn, and several alloys at 22 and 135°C.

Results of viscosity measurements based on the oscillating body type of viscosimeter are reported for steam and compressed water over the range 3–340 atm, and 20–186° [28R]. Shock-tube heat-transfer measurements using thin film thermometry are used to determine high temperature viscosities for dissociated oxygen [14R].

Viscosities of methanol–water mixtures are reported by [26R], accurate to 0–6 per cent over the temperature range 25–50°C.

REFERENCES

List 1. Books

1. H. D. Baehr, *Mollier i-x Diagrams for Humid Air in Units of the International System of Units.* Springer-Verlag, Berlin (1961).
2. C. W. Becket, W. S. Benedict, L. Fano, J. Hilsenrath, H. J. Hoge, J. F. Masi, R. L. Nuttall and Y. S. Touloukian, *Tables of Thermodynamic and Transport Properties of Air, Argon, Carbon Dioxide, Carbon Monoxide, Hydrogen, Nitrogen, and Steam.* Pergamon Press, London (1960).
3. R. B. Bird, W. E. Steward and E. N. Lightfoot, *Transport Phenomena.* John Wiley, New York–London (1960).
4. F. Bošnjaković, *Technische Thermodynamik*, Part II (3rd Ed.). Verlag von Theodor Steinkopff, Dresden (1960).
5. I. W. Busbridge, *The Mathematics of Radiative Transfer.* Cambridge University Press, London (1960)
6. G. K. T. Conn and D. G. Avery, *Infrared Methods.* Academic Press, New York (1960).
7. F. M. Devienne (Ed. by), *Rarefied Gas Dynamics (Proceedings of the First International Symposium, Nice, France, July* 1959). Pergamon Press, New York (1960).
8. E. R. G. Eckert and R. M. Drake, *Theory of Heat and Mass Transfer* (Translation). State Energetics Publishing House, Moscow (1961).
9. N. A. Fuchs, *Evaporation and Droplet Growth in Gaseous Media.* Pergamon Press, New York (1959).
10. B. Gebhart, *Heat Transfer*, McGraw-Hill, New York (1961).
11. A. Goldsmith, T. E. Waterman and J. J. Hirschhorn, *Handbook of Thermophysical Properties of Solid Materials: Vol.* 1, *Elements.* Pergamon Press, New York (1961).
12. I. F. Golubev, *Viscosity of Gases and Gaseous Mixtures: A Reference Manual.* Gosudarstvennoe Izdatel'stvo Fiziko-Matematichoskoi Literatury, Moscow (1959).
13. T. R. Harrison, *Radiation Pyrometry and Its Underlying Principles of Radiant Heat Transfer.* John Wiley, New York (1960).
14. J. P. Hartnett (Editor), *Recent Advances in Heat and Mass Transfer.* McGraw-Hill, New York (1961).
15. W. Haussler, *The Mollier i-x Diagram for Humid Air and Its Technical Application.* Verlag von Theodor Steinkopff, Dresden (1960).
16. R. W. Haywood (Editor), *Thermodynamic Tables and Other Data* (2nd Ed.). Cambridge University Press, New York (1960).

17. P. K. Konakov, *Investigation of Complex Heat Exchange in Thermoenergetic Apparatuses in Railroad Transportation.* Moscow Institute for Railroad Engineers, Moscow (1960).
18. P. K. Konakov, S. S. Filimonov and B. A. Khrustalev, *Heat Exchange in Combustion Chambers of Steam Boilers.* River Transport, Moscow (1960).
19. B. G. Korenev, *Certain Problems in the Theory of Elasticity and Heat Conduction Solved in Terms of Bessel Functions.* Gosudarstvennoe Izdatel'stvo Fiziko-Matematicheskoi Literatury, Moscow (1960).
20. A. V. Luikov, *Theoretical Base of Engineering Thermophysics.* Academy of Science of BSSR, Minsk (1961).
21. D. Meksyn, *New Methods in Laminar Boundary-Layer Theory.* Pergamon Press, New York (1961).
22. W. M. Rohsenow and H. Y. Choi, *Heat, Mass and Momentum Transfer.* Prentice-Hall, New York (1961).
23. H. Schlichting, *Boundary Layer Theory* (4th Ed.). McGraw-Hill, New York (1960).
24. R. W. Truitt, *Fundamentals of Aerodynamic Heating.* Ronald Press, New York (1960).
25. A. I. Veynik, *Approximate Calculation of Heat Conduction Processes.* Gosudarstvennoe Energeticheskoe Izdatel'stov, Moscow (1959).
26. A. I. Veynik, *Thermodynamics.* Ministry of Higher Secondary and Professional Education of BSSR, Minsk (1961).
27. *International Developments in Heat Transfer.* Parts I–V (Papers presented at the 1961 International Heat Transfer Conference, August 28–September 1, 1961, University of Colorado, Boulder, Colorado). American Society of Mechanical Engineers, New York (1961).

Conduction

1A. L. M. Altshuler, *Inzh. Fiz. Zh.* **4,** 64 (1961).
2A. J. T. Anderson, J. M. Botje and W. K. Koffel, *J. Heat Transfer* **C83,** 516 (1961).
3A. S. I. Anisimov and T. L. Perelman, *Int. J. Heat Mass Transfer*, **1,** 269 (1961).
4A. H. R. Bailey, *Quart. Appl. Math.* **18,** 325 (1961).
5A. M. J. Balcerzak and S. Raynor, *Int. J. Heat Mass Transfer*, **3,** 113 (1961).
6A. A. E. Bergles and J. Kaye, *J. Aero. Space Sci.* **28,** 251 (1961).
7A. P. L. T. Brian, *J. Amer. Inst. Chem. Engrs* **7,** 367 (1961).
8A. J. J. Brogan and P. J. Schneider, *J. Heat Transfer* **C83,** 506 (1961).
9A. H. Buchholz, *Z. Angew. Math. Mech.* **41,** 229 (1961).
10A. S.-Y. Chen, *J. Aero. Space Sci.* **28,** 336 (1961).
11A. S. P. Clark, Jr., *J. Geophys. Res.* **66,** 1231 (1961).
12A. R. J. Conti, *N.A.S.A. Tech. Note* D-895 (1961).
13A. J. R. Davidson and J. F. Dalby, *N.A.S.A. Tech. Note* D-520 (1961).
14A. W. O. Doggett and E. L. Arnold, *J. Heat Transfer* **C83,** 423 (1961).
15A. I. G. Donaldson, *Quart. Appl. Math.* **19,** 205 (1961).
16A. C. Duhne, *Brit. Chem. Engng* **6,** 680 (1961).
17A. G. M. Dusinberre, *J. Heat Transfer* **C83,** 94 (1961).
18A. M. R. El-Saden, *J. Heat Transfer* **C83,** 510 (1961).
19A. A. H. El-Waziri, *Iron Steel Engr* **38,** 130 (1961).
20A. N. H. Freed and C. J. Rallis, *J. Heat Transfer* **C83,** 382 (1961).
21A. T. R. Goodman, *J. Heat Transfer* **C83,** 83 (1961).
22A. R. L. Gorring and S. W. Churchill, *Chem. Engng Progr.* **57,** 53 (1961).
23A. A. M. Guenault, *Proc. Roy. Soc.* A**262,** 420 (1961).
24A. G. R. Guinn, *J. Amer. Rocket Soc.* **31,** 158 (1961).
25A. R. S. Harris Jr. and J. R. Davidson, *N.A.S.A. Tech. Note* D-519 (1961).
26A. J. F. Heyda, *Z. Angew. Math. Phys.* **12,** 322 (1961).
27A. G. Horvay, *J. Heat Transfer* **C83,** 391 (1961).
28A. J. Jacq and M. Chateau, *C.R. Acad. Sci., Paris* **252,** 3201 (1961).
29A. C. H. Johnson, *Aust. J. Phys.* **14,** 317 (1961).
30A. D. W. Jordan, *Brit. J. Appl. Phys.* **12,** 14 (1961).
31A. W. I. Kim, *Soviet Fiz. Dokl.* **6,** 760 (1961).
32A. P. K. Konakov, *Int. J. Heat Mass Transfer*, **2,** 136 (1961).
33A. D. Kunii and J. M. Smith, *J. Amer. Inst. Chem. Engrs* **7,** 29 (1961).
34A. T. J. Lardner and F. V. Pohle, *J. Appl. Mech.* **E28,** 310 (1961).
35A. C.-Y. Liu, *Quart. Appl. Math.* **19,** 245 (1961).
36A. A. N. Lowan, *Math. Comput.* **15,** 179 (1961).
37A. G. Lück, *Chem.-Ing.-Tech.* **33,** 547 (1961).
38A. P.-C. Lu, *J. Heat Transfer* **C83,** 512 (1961).
39A. C. E. Lund and R. M. Lander, *ASHRAE J.* **3,** 47 (1961).
40A. V. I. Makhovikov, *Inzh. Fiz. Zh.* **4,** 82 (1961).
41A. K. R. Merckx, *Nucl. Sci. Engng* **10,** 223 (1961).
42A. W. L. Miranker, *Proc. Amer. Math. Soc.* **12,** 243 (1961).
43A. R. E. Nettleton, *Phys. Fluids* **4,** 74 (1961).
44A. A. D. Reich and J. R. Madigan, *J. Appl. Phys.* **32,** 294 (1961).
45A. G. F. C. Rogers, *Int. J. Heat Mass Transfer*, **2,** 150 (1961).
46A. Th. E. Schmidt, *Forsch. Ing.-Wes.* **B27,** 10 (1961).
47A. G. Schneeweiss, *Öst. Ing. Z.* **4,** 49 (1961).
48A. J. P. Sellers, Jr., *J. Amer. Rocket Soc.* **31,** 445 (1961).
49A. D. A. Spence, *Quart. J. Mech. Appl. Math.* **14,** 375 (1961).
50A. D. G. Stephenson and C. J. Shirtliffe, *J. Heat Transfer* **C83,** 514 (1961).
51A. D. W. Stops, *J. Sci. Instrum.* **38,** 262 (1961).
52A. J. E. Sunderland and R. J. Grosh, *J. Heat Transfer* **C83,** 409 (1961).
53A. C. Tien, *Canad. J. Chem. Engng* **39,** 42 (1961).
54A. L. T. Tjoan, *J. Heat Transfer* **C83,** 508 (1961).
55A. P. V. Tsoi, *Inzh. Fiz. Zh.* **4,** 120 (1961).
56A. W. Unterberg, *J. Aero. Space Sci.* **28,** 78 (1961).
57A. V. Vodicka, *Z. Angew. Math. Phys* **12,** 164 (1961).
58A. M. Yamamoto, *J. Phys. Soc. Japan* **16,** 1644 (1961).

Channel flow

1B. R. A. Alpher, *Int. J. Heat Mass Transfer*, **3**, 108 (1961).
2B. L. V. Baldwin and T. J. Walsh, *J. Amer. Inst. Chem. Engrs* **7**, 53 (1961).
3B. H. Barrow, *Int. J. Heat Mass Transfer*, **1**, 306 (1961).
4B. H. Barrow, *J. Mech. Engng Sci.* **2**, 331 (1960).
5B. C. F. Bonilla, J. S. Busch, H. G. Landau and L. L. Lyon, *Nucl. Sci. Engng* **9**, 323 (1961).
6B. D. F. Brewer and D. O. Edwards, *Phil. Mag.* **6**, 775, (1961).
7B. P. Bro and S. Steinberg, *J. Amer. Rocket Soc.* **31**, 375 (1961).
8B. L. W. Carlson and T. F. Irvine, Jr., *J. Heat Transfer* **C83**, 441 (1961).
9B. G. Franke, *Allg. Wärmetech.* **10**, 36 (1961).
10B. G. Franke, *Allg. Wärmetech.* **10**, 49 (1961).
11B. S. Globe, *J. Heat Transfer* **C83**, 445 (1961).
12B. S. C. Gupta, *Appl. Sci. Res.* **A10**, 229 (1961).
13B. S. C. Gupta, *Appl. Sci. Res.* **A10**, 85 (1961).
14B. R. W. Hanks and E. B. Christiansen, *J. Amer. Inst. Chem. Engrs* **7**, 519 (1961).
15B. H. Hartmann, *Chem.-Ing.-Tech.* **33**, 22 (1961).
16B. R. I. Hodge, *J. Heat Transfer* **C83**, 384 (1961).
17B. Y.-Y. Hsu and J. M. Smith, *J. Heat Transfer* **C83**, 176 (1961).
18B. G .A. Kemeny and J. A. Cyphers, *J. Heat Transfer* **C83**, 189 (1961).
19B. J. L. Kerrebrock and R. V. Meghreblian, *J. Aero. Space Sci.* **28**, 710 (1961).
20B. J. J. Keyes, Jr., *J. Amer. Rocket Soc.* **31**, 1204 (1961).
21B. J. J. Keyes, Jr., *Proc. Heat Transfer and Fluid Mech. Inst.* p. 31, Stanford University Press, Calif. (1960).
22B. W. F. Krieve and D. M. Mason, *J. Amer. Inst. Chem. Engrs* **7**, 277 (1961).
23B. O. Krischer, *Chem.-Ing.-Tech.* **33**, 13 (1961).
24B. R. Lemlich and C.-K. Hwu, *J. Amer. Inst. Chem. Engrs* **7**, 102 (1961).
25B. L. M. Mack, *J. Fluid Mech.* **8**, 284 (1960).
26B. A. E. Marenov, *J. Amer. Rocket Soc.* **30**, 1055 (1960).
27B. A. I. Morgan, Jr. and R. A. Carlson, *J. Heat Transfer* **C83**, 105 (1961).
28B. K. Murakawa, *Int. J. Heat Mass Transfer*, **2**, 240 (1961).
29B. S. D. Nigam and H. C. Agrawal, *J. Math. Mech.* **9**, 869 (1960).
30B. S. D. Nigam and S. N. Singh, *Quart. J. Mech. Appl. Math.* **13**, 85 (1960).
31B. R. N. Noyes, *J. Heat Transfer* **C83**, 454 (1961).
32B. R. N. Noyes, *J. Heat Transfer* **C83**, 96 (1961).
33B. S. Pahor and J. Strnad, *Z. Angew. Math. Phys.* **12**, 80 (1961).
34B. S. Pahor and J. Strnad, *Appl. Sci. Res.* **A10**, 81 (1961).
35B. M. Perlmutter and R. Siegel, *N.A.S.A. Tech. Note* D-875 (1961).
36B. M. Perlmutter and R. Siegel, *Int. J. Heat Mass Transfer*, **3**, 94 (1961).
37B. F.-J. Quirrenbach, *Allg. Wärmetch.* **9**, 271 (1960).
38B. A. Reynolds, *Z. Angew. Math. Phys.* **12**, 149 (1961).
39B. A. Reynolds, *Z. Angew. Math. Phys.* **12**, 343 (1961).
40B. G. F. C. Rogers and Y. R. Mayhew, *Int. J. Heat Mass Transfer*, **1**, 55 (1960).
41B. E. M. Rosen and E. J. Scott, *J. Heat Transfer* **C83**, 98 (1961).
42B. J. M. Savino and R. G. Ragsdale, *J. Heat Transfer* **C83**, 33 (1961).
43B. W. R. Schowalter and H. F. Johnstone, *J. Amer. Inst. Chem. Engrs* **6**, 648 (1960).
44B. J. D. Seader and H. Wolf, *J. Amer. Rocket Soc.* **31**, 650 (1961).
45B. J. C. Smith, *Canad. J. Chem. Engng* **39**, 106 (1961).
46B. E. M. Sparrow, A. L. Loeffler Jr. and H. A. Hubbard, *J. Heat Transfer* **C83**, 415 (1961).
47B. K. Stephan, *Ing.-Arch.* **29**, 176 (1960).
48B. K. Stephan, *Chem.-Ing.-Tech.* **32**, 401 (1960).
49B. L. N. Tao, *J. Heat Transfer* **C83**, 466 (1961).
50B. D. G. Thomas, *J. Amer. Inst. Chem. Engrs* **6**, 631 (1960).
51B. C. L. Tien, *Canad. J. Chem. Engng* **39**, 45 (1961).
52B. C. L. Tien, *J. Heat Transfer* **C83**, 183 (1961).
53B. H. Ullrich, *Chem.-Ing.-Tech.* **33**, 606 (1961).
54B. U. H. von Glahn, *N.A.S.A. Tech. Note* D-483 (1960).
55B. E. H. Wissler and R. S. Schechter, *Appl. Sci. Res.* **A10**, 198 (1961).

Boundary-layer flow

1C. A. Acrivos, *Chem. Engng Sci.* **13**, 57 (1960).
2C. A. Acrivos, *Phys. Fluids* **3**, 657 (1960).
3C. A. D. Anderson, *J. Aero. Space Sci.* **28**, 749 (1961).
4C. L. N. Bathish and B. H. Sage, *J. Amer. Inst. Chem. Engrs* **6**, 693 (1960).
5C. I. E. Beckwith, *N.A.S.A. Tech. Rep.* R-107 (1961).
6C. I. E. Beckwith and N. B. Cohen, *N.A.S.A. Tech. Note* D-625 (1961).
7C. P. F. Brinich, *N.A.S.A. Tech. Note* D-1047 (1961).
8C. J. J. Buglia, *N.A.S.A. Tech. Note* D-955 (1961). Supersedes *N.A.C.A. Rep. Mem.* L57D05.
9C. H. S. Carter and R. E. Carr, *N.A.S.A. Tech. Note* D-988 (1961).
10C. R. D. Cess, *J. Heat Transfer* **C83**, 274 (1961).
11C. P. K. Chang and H. B. Nottage, *J. Franklin Inst.* **271**, 445 (1961).
12C. L. T. Chauvin and J. J. Buglia, *N.A.S.A. Tech. Note* D-250 (1960).
13C. S. I. Cheng and H. H. Chiu, *Int. J. Heat Mass Transfer*, **1**, 280 (1961).
14C. P. M. Chung, *N.A.S.A. Rep.* R-109 (1961).
15C. P. M. Chung and A. D. Anderson, *N.A.S.A. Tech. Note* D-350 (1961).
16C. R. J. Conti, *N.A.S.A. Tech. Note* D-962 (1961).
17C. M. Cooper, E. E. Mayo and J. D. Julius, *N.A.S.A. Tech. Note* D-391 (1960).
18C. K. R. Czarnecki and J. R. Sevier, Jr., *N.A.S.A. Tech. Note* D-417 (1960).
19C. R. G. Deissler, *N.A.S.A. Tech. Note* D-680 (1961).
20C. W. D. Deveikis and R. W. Walker, *N.A.S.A. Tech. Note* D-907 (1961).

21C. W. H. Dorrance, *J. Amer. Rocket Soc.* **31,** 61 (1961).
22C. R. Eichhorn, E. R. G. Eckert and R. O. Anderson, *J. Heat Transfer* **C82,** 349 (1960).
23C. R. D. English and H. S. Carter, *N.A.S.A. Tech. Note* D-399 (1960).
24C. R. J. Gribben, *J. Appl. Mech.* **E28,** 339 (1961).
25C. C. R. Gunn, *N.A.S.A. Tech. Note* D-550 (1961).
26C. O. T. Hanna and J. E. Myers, *J. Amer. Inst. Chem. Engrs* **7,** 532 (1961).
27C. O. T. Hanna and J. E. Myers, *J. Amer. Inst. Chem. Engrs* **7,** 437 (1961).
28C. G. R. Inger, *J. Aero. Space Sci.* **27,** 956 (1960).
29C. G. R. Inger, *J. Amer. Rocket Soc.* **30,** 1028 (1960).
30C. J. P. Irving and J. M. Smith, *J. Amer. Inst. Chem. Engrs* **7,** 91 (1961).
31C. C. H. J. Johnson, *Aust. J. Phys.* **14,** 317 (1961).
32C. J. Kestin, P. F. Maeder and H. H. Sogin, *Z. Angew. Math. Phys.* **12,** 115 (1961).
33C. J. Kestin, P. F. Maeder and H. E. Wang, *Int. J. Heat Mass Transfer*, **3,** 133 (1961).
34C. J. C. Y. Koh and J. P. Hartnett, *Int. J. Heat Mass Transfer*, **2,** 185 (1961).
35C. J. Kondo and Y. Yoshizawa, *Proc. 10th Jap. Nat. Congr. Appl. Mech.* p. 197 (1960).
36C. S. I. Kosterin and Yu. A. Koshmarov, *Int. J. Heat Mass Transfer*, **1,** 46 (1960).
37C. Yu. V. Lapin, *Soviet Fiz.-Tekh. Fiz.* **5,** 1162 (1961).
38C. G. Ludwig and M. Heil, *Advances in Applied Mechanics*, Vol. 6, p. 39. Academic Press, New York (1960).
39C. E. D. Martin, *J. Aero. Space Sci.* **28,** 831 (1961).
40C. C. F. Merlet and C. B. Rumsey, *N.A.S.A. Tech. Note* D-951 (1961). Supersedes *N.A.C.A. Rep. Mem.* L56L10.
41C. R. X. Meyer, *Z. Angew. Math. Phys.* **11,** 127 (1960).
42C. Y. Nakagawa and I. R. Goroff, *Phys. Fluids* **4,** 349 (1961).
43C. R. A. Newlander, *N.A.S.A. Tech. Note* D-642 (1961).
44C. S. Ostrach, A. W. Goldstein and J. Hamman, *J. Aero. Space Sci.* **27,** 626 (1960).
45C. R. L. Phillips, *J. Amer. Rocket Soc.* **31,** 672 (1961).
46C. A. A. Pomerantsev, *Int. J. Heat Mass Transfer*, **2,** 8 (1961).
47C. G. Poots and L. Sowerby, *Quart. J. Mech. Appl. Math.* **13,** 385 (1960).
48C. J. L. Potter and J. D. Whitfield, *J. Aero. Space Sci.* **28,** 663 (1961).
49C. A. K. Ray, *Appl. Sci. Res.* **A10,** 173 (1961).
50C. R. I. Rothenberg and J. M. Smith, *Canad. J. Chem. Engng* **38,** 184 (1960).
51C. C. B. Rumsey and D. B. Lee, *N.A.S.A. Tech. Note* D-888 (1961). Supersedes *N.A.C.A. Rep. Mem.* L56F26.
52C. B. C. Sakiadis, *J. Amer. Inst. Chem. Engrs* **7,** 26 (1961).
53C. E. A. Sanlorenzo, *J. Aero. Space Sci.* **28,** 904 (1961).
54C. V. A. Smirnov, G. E. Verevochkin and P. M. Brdlick, *Int. J. Heat Mass Transfer*, **2,** 1 (1961).
55C. A. G. Smith and V. L. Shah, *Int. J. Heat Mass Transfer*, **3,** 126 (1961).
56C. E. M. Sparrow and R. D. Cess, *Appl. Sci. Res.* **A10,** 185 (1961).
57C. D. A. Spence, *J. Aero. Space Sci.* **27,** 878 (1960).
58C. P. C. Stainback, *N.A.S.A. Tech. Note* D-549 (1961).
59C. M. H. Steiger, *J. Aero. Space Sci.* **28,** 579 (1961).
60C. T. Tendeland, H. L. Nielsen and M. J. Fohrman, *N.A.S.A. Tech. Note* D-689 (1961).
61C. R. L. Trimpi and N. B. Cohen, *N.A.S.A. Tech. Rep.* R-85 (1961). Supersedes *N.A.C.A. Tech. Note* 4347.
62C. P. K. Watson, *Nature, Lond.* **189,** 563 (1961).
63C. E. M. Winkler, *J. Appl. Mech.* **E28,** 323 (1961).
64C. R. J. Wisniewski and J. R. Jack, *J. Aero. Space Sci.* **28,** 250 (1961).
65C. J. G. Woodley, *Aero. Res. Counc. Lond., Curr. Pap.* 479 (1960).
66C. C.-S. Wu, *J. Aero Space Sci.* **27,** 882 (1960).
67C. K.-T. Yang, *J. Appl. Mech.* **E28,** 9 (1961).

Flow with separated regions

1D. J. J. Bernard and R. Siestrunck, *Advances in Aeronautical Sciences* (*Proc. First Intl. Congr. Aeronautical Sci.*, Madrid, Sept. 8–13, 1958), Pergamon Press, Vol. 1, pp. 314–332 (1959).
2D. H. Brauer, *Chem.-Ing.-Tech.* **33,** 431 (1961).
3D. H. Brauer, *Kältetechnik* **13,** 274 (1961).
4D. A. F. Charwat, C. F. Dewey, Jr., J. N. Roos and J. A. Hitz, *J. Aero. Space Sci.* **28,** 513 (1961).
5D. P. M. Chung and J. R. Viegas, *N.A.S.A. Tech. Note* D-1072 (1961).
6D. J. F. Frantz, *Chem. Engng Progr.* **57,** 35 (1961).
7D. J. G. Hall and T. C. Golian, *J. Aero. Space Sci.* **28,** 345 (1961).
8D. J. C. Y. Koh and J. P. Hartnett, *J. Amer. Rocket Soc.* **31,** 71 (1961).
9D. O. Krischer, *Chem.-Ing.-Tech.* **33,** 155 (1961).
10D. P. N. Kubanski, *Acoustics J.* **7,** 313 (1961).
11D. D. Kunii and J. M. Smith, *J. Amer. Inst. Chem. Engrs* **6,** 71 (1960).
12D. D. Kunii and J. M. Smith, *J. Amer. Inst. Chem. Engrs* **7,** 29 (1961).
13D. H. K. Larson and S. J. Keating, Jr., *N.A.S.A. Tech. Note* D-349 (1960).
14D. D. G. McConnell, *N.A.S.A. Tech. Note* D-278 (1961).
15D. K. Nakamura and M. Nakatani, *Bull. Japan Soc. Mech. Engrs* **4,** 554 (1961).
16D. I. S. Pasternak and W. H. Gauvin, *Canad. J. Chem. Engng* **38,** 35 (1960).
17D. E. Purves and R. S. Brodkey, *J. Amer. Inst. Chem. Engrs* **7,** 531 (1961).
18D. K. Sreenivasan and A. Ramachandran, *Int. J. Heat Mass Transfer*, **3,** 60 (1961).
19D. G. C. Vliet and G. Leppert, *J. Heat Transfer* **C83,** 163 (1961).
20D. C. B. Von Der Decken, H. J. Hantke, J. Binckebanck and K. P. Bachus, *Chem.-Ing.-Tech.* **32,** 591 (1960).

21D. S. Yagi, D. Kunii and N. Wakao, *J. Amer. Inst. Chem. Engrs* **6**, 543 (1960).

22D. S. Yagi and N. Wakao, *J. Amer. Inst. Chem. Engrs* **5**, 79 (1959).

Transfer mechanisms

1E. G. M. Abramovich, B. G. Khudenko and I. S. Makarov, *Int. J. Heat Mass Transfer*, **3**, 84 (1961)

2E. L. V. Baldwin and T. J. Walsh, *J. Amer. Inst. Chem. Engrs* **7**, 53 (1961).

3E. R. Betchov, *Phys. Fluids* **3**, 1026 (1960).

4E. E. A. Betz, *Z. Flugw.* **9**, 20 (1961).

5E. L. J. Challis, K. Dransfeld and J. Wilks, *Proc. Roy. Soc.* A**259**, 31 (1961).

6E. R. G. Deissler, *N.A.S.A. Tech. Rept.* R-96 (1961).

7E. R. A. Granville and G. Boxall, *Brit. J. Appl. Phys.* **11**, 471 (1960).

8E. A. L. Loeffler Jr. and R. G. Deissler. *Int. J. Heat Mass Transfer*, **1**, 312 (1961).

9E. M. Mochizuki, *J. Phys. Soc. Japan* **16**, 995 (1961).

10E. E. A. Novikov, *Proc. Acad. Sci. USSR* **139**, 331 (1961).

11E. R. G. Ragsdale, *N.A.S.A. Tech. Note* D-1051 (1961).

12E. R. E. Rosensweig, H. C. Hottel and G. C. Williams, *Chem. Engng Sci.* **15**, 111 (1961).

13E. W. G. Spangenberg and W. R. Rowland, *Phys. Fluids* **3**, 667 (1960).

14E. W. Squire, *Int. J. Heat Mass Transfer*, **3**, 155 (1961).

15E. A. A. Townsend, *J. Fluid Mech.* **11**, 97 (1961).

16E. L. M. Vaughan, *J. Meteorl.* **18**, 43 (1961).

Natural convection

1F. A. Acrivos, *J. Amer. Inst. Chem. Engrs* **6**, 584 (1960).

2F. W. H. Braun, S. Ostrach and J. E. Heighway, *Int. J. Heat Mass Transfer*, **2**, 121 (1961).

3F. J. Brindley, *Phil. Trans.* A**253**, 1020, 1 (1960).

4F. P. M. Chung and A. D. Anderson, *J. Heat Transfer* C**83**, 473 (1961).

5F. K. R. Cramer, *J. Aero. Space Sci.* **28**, 736 (1961).

6F. E. R. G. Eckert and W. O. Carlson, *Int. J. Heat Mass Transfer* **2**, 106, (1961).

7F. R. M. Fand and J. Kaye, *J. Heat Transfer* C**83**, 133 (1961).

8F. F. H. Garner and J. M. Hoffman, *J. Amer. Inst. Chem. Engrs* **7**, 148 (1961).

9F. F. H. Garner and J. M. Hoffman, *J. Amer. Inst. Chem. Engrs* **6**, 579 (1960).

10F. B. Gebhart, *J. Heat Transfer* C**83**, 61 (1961).

11F. H. W. Hahnemann, *Z. Ver. Dtsch. Ing.* **102**, 1789 (1960).

12F. J. P. Holman, *J. Heat Transfer* C**82**, 393 (1960).

13F. T. W. Jackson and E. E. Söhngen, *Chem.-Ing.-Tech.* **33**, 536 (1961).

14F. T. W. Jackson, J. M. Spurlock and K. R. Purdy, *J. Amer. Inst. Chem. Engrs* **7**, 38 (1961).

15F. H. L. Kuo, *J. Fluid Mech.* **10**, 611 (1961).

16F. F. W. Larsen and J. P. Hartnett, *J. Heat Transfer* C**83**, 87 (1961).

17F. R. Lemich and M. R. Levy, *J. Amer. Inst. Chem. Engrs* **7**, 240 (1961).

18F. P.-C. Lu, *J. Appl. Mech.* E**28**, 454 (1961).

19F. B. Metais, *Chem.-Ing.-Tech.* **32**, 535 (1960).

20F. Y. Mori, *J. Heat Transfer* C**83**, 479 (1961).

21F. K. Murakawa, *Bull. Japan Soc. Mech. Engrs* **4**, 347 (1961).

22F. G. Poots, *Int. J. Heat Mass Transfer*, **3**, 1 (1961).

23F. A. K. Rao, *Appl. Sci. Res.* A**10**, 141 (1961).

24F. B. L. Reeves, *J. Amer. Rocket Soc.* **31**, 557 (1961).

25F. E. M. Rosen and T. J. Hanratty, *J. Amer. Inst. Chem. Engrs* **7**, 112 (1961).

26F. G. F. Scheele, E. M. Rosen and T. J. Hanratty, *Canad. J. Chem. Engng* **38**, 67 (1960).

27F. H. Senftleben, *Allg. Wärmetech.* **10**, 192 (1961).

28F. A. Sesonske, *J. Amer. Inst. Chem. Engrs* **7**, 352 (1961).

29F. G. F. Shaidurov, *Int. J. Heat Mass Transfer*, **2**, 280 (1961).

30F. D. B. Spalding and R. G. Cruddace, *Int. J. Heat Mass Transfer*, **3**, 55 (1961).

31F. E. M. Sparrow and R. D. Cess, *J. Heat Transfer* C**83**, 387 (1961).

32F. S. P. Talwar, *J. Fluid Mech.* **9**, 581 (1960).

33F. W. R. Wilcox, *Chem. Engng Sci.* **13**, 113 (1961).

34F. C.-S. Yih, *Phys. Fluids* **4**, 806 (1961).

35F. J. Zierep, *Z. Angew. Math. Mech.* **41**, 114 (1961).

Convection from rotating surfaces

1G. D. R. Davies and C. B. Baxter, *Quart. J. Mech. Appl. Math.* **14**, 223 (1961).

2G. J. P. Hartnett and E. C. Deland, *J. Heat Transfer* C**83**, 95 (1961).

3G. P. D. Richardson, *J. Heat Transfer* C**83**, 386 (1961).

4G. C. L. Tien, *J. Heat Transfer* C**82**, 252 (1960).

5G. C. L. Tien, *J. Heat Transfer* C**83**, 514 (1961).

Combined heat and mass transfer

1H. E. P. Bartlett and M. R. Denison, *J. Heat Transfer* C**83**, 457 (1961).

2H. N. Beecher and R. E. Rosensweig, *J. Amer. Rocket Soc.* **31**, 532 (1961).

3H. R. P. Bernicker, *J. Aero. Space Sci.* **28**, 658 (1961).

4H. S. Blecher and G. W. Sutton, *J. Amer. Rocket Soc.* **31**, 433 (1961).

5H. J. H. Chin, S. C. Skirvin, L. E. Hayes and F. Burggraf, *J. Heat Transfer* C**83**, 281 (1961).

6H. P. M. Chung, *N.A.S.A. Tech. Note* D-141 (1960).

7H. M. R. Denison, *J. Aero. Space Sci.* **28**, 471 (1961).

8H. H. L. Evans, *Int. J. Heat Mass Transfer*, **3**, 26 (1961).

9H. F. H. Gayner and J. M. Hoffman, *J. Amer. Inst. Chem. Engrs* **6**, 579 (1960).

10H. J. P. Hartnett, R. C. Birkebak and E. R. G. Eckert, *J. Heat Transfer* C**83**, 293 (1961).

11H. M. F. Kazansky, P. P. Lutsick and V. N. Oleynikov, *Int. J. Heat Mass Transfer*, **2**, 231 (1961).

12H. J. C. Y. Koh and J. P. Hartnett, *Int. J. Heat Mass Transfer*, **2**, 185 (1961).

13H. I. Kubota, *J. Amer. Rocket Soc.* **30**, 1164 (1960).

14H. P. D. Lebedev, *Int. J. Heat Mass Transfer*, **1**, 294 (1961).

15H. P. D. Lebedev, *Int. J. Heat Mass Transfer*, **1**, 302 (1961).

16H. P. A. Libby and R. J. Cresci, *J. Aero. Space Sci.* **28**, 51 (1961).

17H. Y. Mikhailov, *Int. J. Heat Mass Transfer* **1**, 37 (1960).

18H. N. Ness, *J. Aero. Space Sci.* **28**, 645 (1961).

19H. A. Pallone, *J. Aero. Space Sci.* **28**, 449 (1961).

20H. A. V. Ralko, *Int. J. Heat Mass Transfer*, **1**, 273 (1961).

21H. R. A. Seban, *J. Heat Transfer* **C82**, 392 (1960).

22H. R. A. Seban, *J. Heat Transfer* **C82**, 303 (1960).

23H. H. H. Sogin and V. S. Subramanian, *J. Heat Transfer* **C83**, 483 (1961).

24H. D. B. Spalding and H. L. Evans, *Int. J. Heat Mass Transfer*, **2**, 199 (1961).

25H. D. B. Spalding, *Int. J. Heat Mass Transfer*, **2**, 283 (1961).

26H. D. B. Spalding and H. L. Evans, *Int. J. Heat Mass Transfer*, **2**, 314 (1961).

27H. B. L. Swenson, *N.A.S.A. Tech. Note* D-861 (1961).

28H. D. L. Turcotte, *J. Fluid Mech.* **8**, 123 (1960).

29H. C. H. E. Warren, *J. Fluid Mech.* **8**, 400 (1960).

Change of phase

1J. W. D. Allingham and J. A. McEntire, *J. Heat Transfer* **C83**, 71 (1961).

2J. J. A. R. Bennett, J. G. Collier, H. R. C. Pratt and J. D. Thornton, *Trans. Inst. Chem. Engrs* **39**, 113 (1961).

3J. R. D. Cess and E. M. Sparrow, *J. Heat Transfer* **C83**, 370 (1961).

4J. R. D. Cess and E. M. Sparrow, *J. Heat Transfer* C83, 377 (1961).

5J. M. M. Chen, *J. Heat Transfer* **C83**, 48 (1961).

6J. M. M. Chen, *J. Heat Transfer* **C83**, 55 (1961).

7J. R. L. Clark and L. A. Bromley, *Chem. Engng Progr.* **57**, 64 (1961).

8J. W. G. Courtney, *J. Amer. Rocket Soc.* **31**, 751 (1961).

9J. E. J. Davis and M. M. David, *Canad. J. Chem. Engng* **39**, 99 (1961).

10J. K. Feind, *Z. Ver. Dtsch. Ing.* **103**, 1434 (1961).

11J. T. Frederking, *Forsch. Ing.-Wes.* **27**, 17 (1961).

12J. K. F. Gordon, T. Singh and E. Y. Weissman, *Int. J. Heat Mass Transfer*, **3**, 90 (1961).

13J. G. Houghton, *Nucl. Sci. Engng* **11**, 121 (1961).

14J. S. T. Hsu and F. W. Schmidt, *J. Heat Transfer* **C83**, 254 (1961).

15J. Y.-Y. Hsu and R. W. Graham, *N.A.S.A. Tech. Note* D-594 (1961).

16J. H. S. Isbin, R. Vanderwater, H. Fauske and S. Singh, *J. Heat Transfer* **C83**, 149 (1961).

17J. W. Jost, *Z. Flugw.* **9**, 104 (1961).

18J. J. C. Y. Koh, *J. Heat Transfer* **C83**, 359 (1961).

19J. J. C. Y. Koh, E. M. Sparrow and J. P. Hartnett, *Int. J. Heat Mass Transfer*, **2**, 69 (1961).

20J. V. V. Konsetov, *Inzh. Fiz. Zh.* **3**, 9 (1960).

21J. R. P. Larkins, R. R. White and D. W. Jeffrey, *J. Amer. Inst. Chem. Engrs* **7**, 231 (1961).

22J. S. Levy, *J. Heat Transfer* **C82**, 113 (1960).

23J. A. J. Madden and F. J. Halfen, *J. Amer. Inst. Chem. Engrs* **7**, 160 (1961).

24J. P. W. McFadden and R. J. Grosh, *Int. J. Heat Mass Transfer*, **1**, 325 (1961).

25J. O. J. Mendler, A. S. Rathbun, N. E. Van Huff and A. Weiss, *J. Heat Transfer* **C83**, 261 (1961).

26J. H. Merte Jr. and J. A. Clark, *J. Heat Transfer* **C83**, 233 (1961).

27J. V. V. Mirkovich and R. W. Missen, *Canad. J. Chem. Engng* **39**, 86 (1961).

28J. K. Nishikawa, *Bull. Japan Soc. Mech. Engrs* **4**, 115 (1961).

29J. K. Niu, *J. Phys. Soc. Japan* **16**, 798 (1961).

30J. V. S. Novoselov, *J. Amer. Rocket Soc.* **31**, 686 (1961).

31J. P. Sachs and R. A. K. Long, *Int. J. Heat Mass Transfer*, **2**, 222 (1961).

32J. E. M. Sparrow and E. R. G. Eckert, *J. Amer. Inst. Chem. Engrs* **7**, 473 (1961).

33J. E. M. Sparrow and J. P. Hartnett, *J. Heat Transfer* **C83**, 101 (1961).

34J. W. G. Steltz, *J. Engng Power* **A83**, 145 (1961).

35J. C. M. Usiskin and R. Siegel, *J. Heat Transfer* **C83**, 243 (1961).

36J. J. J. van Deemter and E. T. Van der Laan, *Appl. Sci. Res.* **A10**, 102 (1961).

37J. I. P. Vichnev and N. K. Elukin, *Inzh. Fiz. Zh.* **3**, 74 (1960).

38J. R. Viskanta, *Nucl. Sci. Engng* **10**, 202 (1961).

39J. G. B. Wallis and J. H. Heasley, *J. Heat Transfer* **C83**, 363 (1961).

40J. W. Wilke, *Kältetechnik* **13**, 339 (1961).

41J. T. Woodward, *Chem. Engng Progr.* **57**, 52 (1961).

42J. N. Zuber, *J. Heat Transfer* **C82**, 255 (1960).

Radiation

1K. W. R. Anderson and I. B. Berlman, *J. Opt. Soc. Amer.* **51**, 1229 (1961).

2K. H. E. Bennett and J. O. Porteus, *J. Opt. Soc. Amer.* **51**, 123 (1961).

3K. J. T. Bevans, *J. Heat Transfer* **C83**, 226 (1961).

4K. J. R. Branstetter, *N.A.S.A. Tech. Note* D-1088 (1961).

5K. M. J. Brunner, *J. Amer. Rocket Soc.* **31**, 1102 (1961).

6K. A. J. Bushman, Jr. and C. M. Pittman, *N.A.S.A. Tech. Note* D-944 (1961).

7K. F. G. Cunningham, *N.A.S.A. Tech. Note* D-710 (1961).

8K. E. R. G. Eckert and E. M. Sparrow, *Int. J. Heat Mass Transfer*, **3**, 42 (1961).

9K. D. K. Edwards, *J. Amer. Rocket Soc.* **31**, 1548 (1961).

10K. D. K. Edwards and K. E. Nelson, *J. Amer. Rocket Soc.* **31**, 1021 (1961).

11K. D. K. Edwards, J. T. Gier, K. E. Nelson and R. D. Roddick, *J. Opt. Soc. Amer.* **51**, 1279 (1961).

12K. R. Gordon, *J. Amer. Ceramic Soc.* **44**, 305 (1961).

13K. R. Goulard, *J. Aero. Space Sci.* **28,** 158 (1961).
14K. I. Granet and W. McIlroy, *J. Amer. Rocket Soc.* **31,** 80 (1961).
15K. F. J. Grove, *J. Amer. Ceramic Soc.* **44,** 317 (1961).
16K. P. G. Guest, *Rev. Sci. Instrum* **32,** 164 (1961).
17K. L. Harris and P. Fowler, *J. Opt. Soc. Amer.* **51,** 164 (1961).
18K. P. L. Hartman and R. C. Merrill, *J. Opt. Soc. Amer.* **51,** 168 (1961).
19K. J. T. Howe, *N.A.S.A. Tech. Rept.* R-95 (1961).
20K. J. T. Howe, *N.A.S.A. Tech Note* D-1031 (1961).
21K. L. P. Kadanoff, *J. Heat Transfer* C**83,** 215 (1961).
22K. H. Kennet and S. L. Strack, *J. Amer. Rocket Soc.* **31,** 370 (1961).
23K. B. Kivel, *J. Aero. Space Sci.* **28,** 96 (1961).
24K. C. Y. Liu, *Quart. Appl. Math.* **19,** 72 (1961).
25K. L. D Nichols, *N.A.S.A. Tech. Note* D-578 (1961).
26K. W. J. O'Sullivan Jr. and W. R. Wade, *N.A.S.A. Tech. Rept.* R-90 (1961).
27K. E. W. Parkes, *Int. J. Heat Mass Transfer*, **2,** 155 (1961).
28K. P. M. Reynolds, *Brit. J. Appl. Phys.* **12,** 111 (1961).
29K. T. Satō, K. Ueda, K. Ōhira *et al.*, *Trans. Japan Soc. Mech. Engrs* **27,** 713 (1961).
30K. E. M. Sparrow, E. R. G. Eckert and T. F. Irvine, Jr., *J. Aero. Space Sci.* **28,** 763–772, 778 (1961).
31K. E. M. Sparrow and J. L. Gregg, *J. Heat Transfer* C**83,** 494 (1961).
32K. E. M. Sparrow, J. L. Gregg, J. V. Szel and P. Manos, *J. Heat Transfer* C**83,** 207 (1961).
33K. E. M. Sparrow, C. M. Usiskin and H. A. Hubbard, *J. Heat Transfer* C**83,** 199 (1961).
34K. R. T. Swann, *J. Aero. Space Sci.* **28,** 582 (1961).
35K. R. H. Tourin, *J. Opt. Soc. Amer.* **51,** 799 (1961).
36K. R. H. Tourin, *J. Opt. Soc. Amer.* **51,** 175 (1961).
37K. R. Viskanta and R. J. Grosh *J. Amer. Rocket Soc.* **31,** 839 (1961).
38K. C. S. Williams, *J. Opt. Soc. Amer.* **51,** 564 (1961).

Liquid metals

1L. A. A. Andreevskii, *Soviet Zh. Atomic. Energ.* **7,** 745 (1961).
2L. N. Z. Azer and B. T. Chao, *Int. J. Heat Mass Transfer*, **3,** 77 (1961).
3L. D. K. Edwards and D. M. Tellep, *J. Amer. Rocket Soc.* **31,** 652 (1961).
4L. A. J. Friedland and C. F. Bonilla, *J. Amer. Inst. Chem. Engrs* **7,** 107 (1961).
5L. W. N. Gill, R. P. Vanek and C. S. Grove, Jr., *J. Amer. Inst. Chem. Engrs* **7,** 216 (1961).
6L. F. G. Hammitt and E. M. Brower, *J. Engng Power* A**83,** 170 (1961).
7L. J. S. McDonald and T. J. Connolly, *Nucl. Sci. Engng* **8,** 369 (1960).
8L. B. S. Petukhov and A. J. Lushin, *Soviet Fiz. Dokl.* **6,** 159 (1961).
9L. B. S. Petukhov and F. F. Tsvetkov, *Inzh. Fiz. Zh.* **4,** 10 (1961).

Low-density heat transfer

1M. S. Abarbanel, *J. Aero. Space Sci.* **28,** 299 (1961).
2M. L. Dumitrescu, *Rev. Mécan. Appl.* **4,** 237 (1959).
3M. T. Fujimoto and K. Takao, *Bull. Japan Soc. Mech. Engrs* **2,** 197 (1959).
4M. Yu. N. Lunkin, *N.A.S.A.* TT F-28 (1960).
5M. H. T. Nagamatsu and T. Y. Li, *Phys. Fluids* **3,** 140 (1960).
6M. S. E. Neice, R. W. Rutowski and K. K. Chan, *J. Aero. Space Sci.* **27,** 387 (1960).
7M. G. N. Patterson and A. K. Sreekanth, *Canad. Aero. J.* **7,** 13 (1961).
8M. A. A. Pomerantsev, *Inzh. Fiz. Zh.* **3,** 3 (1960).
9M. P. P. Wegener and H. Ashkenas, *J. Fluid Mech.* **10,** 550 (1961).

Measurement techniques

1N. C. R. Barber and W. Blanke, *J. Sci. Instrum.* **38,** 17 (1961).
2N. J. E. Bauerle, *Rev. Sci. Instrum.* **32,** 313 (1961).
3N. E. A. Brown, R. J. Charlson and D. L. Johnson, *Rev. Sci. Instrum.* **32,** 984 (1961).
4N. J. W. Daiber, *J. Aero. Space Sci.* **27,** 836 (1960).
5N. R. Eichhorn, *J. Heat Transfer* C**83,** 379 (1961).
6N. R. Gardon, *J. Heat Transfer* C**82,** 396 (1960).
7N. G. E. Glawe, R. C. Johnson and L. N. Krause, *N.A.S.A. Tech. Note* D-870 (1961).
8N. M. L. Gupta, *J. Sci. Industr. Res.* **19**B, 240 (1960).
9N. R. A. Hanel, *N.A.S.A. Tech. Note* D-500 (1960).
10N. J. C. Harper, *Rev. Sci. Instrum.* **32,** 425 (1961).
11N. H. J. Hoge, *Rev. Sci. Instrum.* **32,** 1 (1961).
12N. A. D. Maude, *Brit. J. Appl. Phys.* **12,** 293 (1961).
13N. D. E. McCarthy, *J. Opt. Soc. Amer.* **51,** 801 (1961).
14N. J. C. Morris, *J. Opt. Soc. Amer.* **51,** 798 (1961).
15N. M. R. Nadler and C. P. Kempter, *Rev. Sci. Instrum.* **32,** 42 (1961).
16N. F. Schultz-Grunow and G. Wortberg, *Int. J. Heat Mass Transfer*, **2,** 56 (1961).
17N. F. S. Simmons, A. G. DeBell and Q. S. Anderson, *Rev. Sci Instrum.* **32,** 1265 (1961).
18N. J. H. Siviter and H. Kurt, *N.A.S.A. Tech. Note* D-617 (1960).
19N. D. W. Stops, *J. Sci. Instrum.* **38,** 221 (1961).
20N. C. M. Stover, *Rev. Sci. Instrum.* **32,** 366 (1961).
21N. R. E. Walker and S. E. Grenleski, Jr., *J. Amer. Rocket Soc.* **31,** 77 (1961).
22N. B. Yates and C. H. Panter, *J. Sci. Instrum.* **38,** 196 (1961).

Heat exchangers

1P. D. R. Baker and H. A. Shryock, *J. Heat Transfer* C**83,** 339 (1961).
2P. K. S. Lee and J. G. Knudsen, *J. Amer. Inst. Chem. Engrs* **6,** 669 (1960).
3P. R. Lemlich, *J. Heat Transfer* C**83,** 385 (1961).
4P. E. A. D. Saunders, *Industr. Chem.* **37,** 285 (1961).
5P. E. A. D. Saunders, *Industr. Chem.* **37,** 339 (1961).
6P. W. F. Schalwijk, *J. Engng Power* A**81,** 142 (1959).
7P. W. Smith and A. Poll, *Brit. Chem. Engng* **6,** 614 (1961).
8P. S. L. Sullivan Jr. and C. D. Holland, *Industr. Engng Chem.* **53,** 285 (1961).
9P. S. L. Sullivan Jr. and C. D. Holland, *Industr. Engng Chem.* **53,** 699 (1961).

10P. F. L. Test, *J. Heat Transfer* **C83,** 39 (1961).
11P. C. Y. Wen and E. N. Miller, *Industr. Engng Chem.* **53,** 51 (1961).
12P. W. J. Yang, *Trans. Japan Soc. Mech. Engrs* **27,** 730 (1961).
13P. W. J. Yang, J. A. Clark and V. S. Arpaci, *J. Heat Transfer* **C83,** 321 (1961).

Aircraft and space vehicles

1Q. M. J. Brunner, *J. Amer. Rocket Soc.* **31,** 1102 (1961).
2Q. F. C. Grant, *N.A.S.A. Tech. Note* D-452 (1960).
3Q. O. A. Kelley, Jr., *Aero. Space Engng* **19,** 40 (1960).
4Q. H. P. Kirchner and F. A. Vassallo, *J. Soc. Autom. Engrs* **69,** 96 (1961).
5Q. H. Mark and S. Ostrach, *Aero. Space Engng.* **20,** 10 (1961).
6Q. E. Mayer, *J. Amer. Rocket Soc.* **31,** 911 (1961).
7Q. R. F. Neu, *N.A.S.A. Tech. Note* D-286 (1960).
8Q. W. S. Pellini, *J. Metals* **12,** 952 (1960).
9Q. W. C. Ragsdale and J. M. Smith, *Chem. Engng Sci.* **11,** 242 (1960).
10Q. F. Reeves, P. Cochran and R. P. Dengler, *N.A.S.A. Tech. Note* D-1046 (1961).
11Q. W. H. Robbins, D. Bachkin and A. A. Medeiros, *N.A.S.A. Tech. Note* D-482 (1960).
12Q. L. Roberts, *N.A.S.A. Tech. Note* R-62 (1960).
13Q. C. L. Walker, C. R. Smith and D. G. Britton, *Proc. Heat Transfer and Fluid Mech. Inst.* (June 15–17, 1960) p. 244. Stanford University Press, Calif. (1960).
14Q. L. D. Wing, *Aero. Space Engng* **19,** 58 (1960).
15Q. L. D. Wing and K. E. Cameron, *J. Amer. Rocket Soc.* **13,** 327 (1961).
16Q. M. J. Zucrow and J. P. Sellers, Jr., *J. Amer. Rocket Soc.* **31,** 668 (1961).

Thermodynamic and transport properties

1R. W. L. Bade, E. A. Mason and K. S. Yun, *J. Amer. Rocket Soc.* **31,** 1151 (1961).
2R. F. H. Brock, *J. Amer. Rocket Soc.* **31,** 265 (1961).
3R. R. S. Brokaw, *N.A.S.A. Tech. Rept.* R-81 (1961).
4R. R. F. Bukacek and R. E. Peck, *J. Amer. Inst. Chem. Engrs* **7,** 453 (1961).
5R. J. S. Busch and L. N. Canjar, *J. Amer. Inst. Chem. Engrs* **7,** 343 (1961).
6R. R. Byrne and G. Thodos, *J. Amer. Inst. Chem. Engrs* **7,** 185 (1961).
7R. E. J. Couch, K. A. Kobe, L. J. Hirth and K. A. Kobe, *J. Chem. Engng Data* **6,** 299 (1961).
8R. E. R. Davidson, *J. Chem. Phys.* **34,** 1240 (1961).
9R. H. Geier and K. Schafer, *Allg. Wärmetech.* **10,** 70 (1961).
10R. C. D. Gopalarathnam, H. E. Hoelscher and G. S. Laddha, *Amer. Inst. Chem. Engrs* **7,** 249 (1961).
11R. P. Gray and P. G. Wright, *Proc. Roy. Soc.* **A263,** 161 (1961).
12R. W. S. Groenier and G. Thodos, *J. Chem. Engng Data* **6,** 240 (1961).
13R. C. F. Hansen and M. E. Hodge, *N.A.S.A. Tech. Note* D-352 (1961).
14R. R. A. Hartunian and P. V. Marrone, *Phys. Fluids* **4,** 535 (1961).
15R. E. Helfand and S. Rice, *J. Chem. Phys.* **32,** 1642 (1960).
16R. J. O. Hirschfelder, M. H. Taylor, T. Kihara and R. Rutherford, *Phys. Fluids* **4,** 663 (1961).
17R. M. Hoch and H. L. Johnston, *J. Phys. Chem.* **65,** 1184 (1961).
18R. K. M. Joshi and S. C. Saxena, *Physica* **27,** 329 (1961).
19R. T. L. Kang, L. J. Hirth, K. A. Kobe and J. J. McKetta, *J. Chem. Engng Data* **6,** 220 (1961).
20R. T. L. Kang and J. J. McKetta, *J. Amer. Inst. Chem. Engrs* **7,** 418 (1961).
21R. L. D. Kaplan, *Planet. Space Sci.* **8,** 23 (1961).
22R. D. D. Konowalow and J. O. Hirschfelder, *Phys. Fluids* **4,** 629 (1961).
23R. L. P. Krudin, *J. Exper. Theor. Phys.* **40,** 1134 (1961).
24R. O. Lutz, *Z. Flugw.* **9,** 113 (1961).
25R. E. Meeron, *Phys. Rev.* (Second Series) **124,** 308 (1961).
26R. S. Z. Mikhail and W. R. Kimel, *J. Chem. Engng Data* **6,** 533 (1961).
27R. D. Misic and G. Thodos, *J. Amer. Inst. Chem. Engrs* **7,** 264 (1961).
28R. J. R. Moszynski, *J. Heat Transfer* **C83,** 111 (1961).
29R. J. L. Novotny and T. F. Irvine, Jr., *J. Heat Transfer* **C83,** 125 (1961).
30R. E. S. Nowak, R. J. Grosh and P. E. Liley, *J. Heat Transfer* **C83,** 1 (1961).
31R. E. S. Nowak, R. J. Grosh and P. E. Liley, *J. Heat Transfer* **C83,** 14 (1961).
32R. E. J. Owens and G. Thodos, *J. Amer. Inst. Chem. Engrs* **6,** 676 (1960).
33R. W. J. Parker, R. J. Jenkins, C. P. Butler and G. L. Abbott, *J. Appl. Phys.* **32,** 1679 (1961).
34R. T.-C. Peng and W. F. Ahtye, *N.A.S.A. Tech. Note* D-687 (1961)
35R S. C. Saxena and S. M. Dave, *Rev. Mod. Phys.* **33,** 148 (1961).
36R. B. N. Srivastava and A. K. Barua, *J. Chem. Phys.* **35,** 329 (1961).
37R. M. E. Stephenson Jr. and M. Mark, *ASHRAE J.* **3,** 75 (1961).
38R. T. S. Storvick and J. M. Smith, *J. Chem. Engng Data* **6,** 28 (1961).
39R. A. M. P. Tans, *Industr. Chem.* **37,** 480 (1961).
40R. E. Thornton, *Proc. Phys. Soc.* **77,** 1166 (1961).
41R. G. T.-N. Tsao, *Industr. Engng Chem.* **53,** 395 (1961).
42R. B. L. Turlington and J. J. McKetta, *J. Amer. Inst. Chem. Engrs* **7,** 336 (1961).
43R. H. Ziebland, *Int. J. Heat Mass Transfer,* **2,** 273 (1961).
44R. H. Ziebland and J. T. A. Burton, *J. Chem. Engng Data* **6,** 579 (1961).
45R. H. Ziebland and M. T. Dupree, *J. Amer. Rocket Soc.* **6,** 845 (1961).