Workshop on Thermal Aspects of Fluid Film Lubrication—A Summary

A Workshop on Thermal Problems in Tribology was held during May 18–20, 1988 at the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology, Atlanta, Georgia. The project received endorsement from the Research Committee of Tribology of the ASME and was sponsored by the National Science Foundation Tribology Program and by the Wright Aeronautical Laboratories of the U.S. Air Force.

1.0 Background

The status of thermal solutions in fluid film tribology is in striking contrast to the status of isothermal solutions. Starting with the early fifties and the introduction of high-speed computers, the solution of the basic differential equation of isothermal lubrication, the Reynolds Equation, has become almost routine. To secure results for journal and thrust bearings of any of a number of configurations, one can turn to numerous papers and texts that contain such isothermal solutions.

But isothermal solutions at best represent only a severe approximation to bearing operation. The course of thermal analysis in tribology is in a state of great uncertainty; there is no body of results to which one could turn to find ready answers to the thermal performance of given journal or thrust bearing. The difficulties responsible for this state of affairs are due, on the one hand, to the multiplicity of variables involved in the process and, on the other hand, to the difficulty of so formulating the problem that the results would be sufficiently general and could be applied to systems other than that for which a given solution was obtained.

Both of these issues are intrinsically related to the fact that the fluid film does not function in isolation but is embedded in an assembly of components—runner, bearing shell, housing pedestal, and other heat sources and sinks. The above issues are tied to the question of thermal boundary conditions. These have to be specified at several locations, including:

* Inlet to the pad
* The sides of the film
* The runner surface
* The bearing surface
* The cavitation region
* The region of reverse flow

There are, also, various modes of heat transfer which may be included or ignored—and their individual importance depends on the application. Thus, the analytical complexities are quite extensive and correspondingly the state of analysis of the thermal problem is incomplete and often contradictory.

Nor is the situation much better in the experimental field. Most experiments are conducted in circumstances specific to a particular test rig. Since the peripheral equipment and the mode of assembly influence the heat transfer pattern, it is difficult to generalize such results to cases where the environment is different. While load capacity measurements are little affected by the systems, thermal effects in fluid films are very sensitive to these factors. Consequently, compared with the body of test results on other facets of tribology such as load capacity, flow, etc., good experiments on temperature mapping and heat flow are scarce.

2.0 Thermal Workshop

2.1 Scope and Objectives. The background to the convening of the workshop was a conviction that there was a need to alleviate the stalemate prevailing in the field of solving thermal problems in tribology. No bearing or seal is isothermal and variable viscosity inherent in their operation must be considered for at least three important reasons.

* Ordinary performance parameters such as power consumption, film thickness and flow, depend on a knowledge of the temperature field.
* Thermoelastic effects are important in the evaluation of film thickness and traction in concentrated contracts.
* Knowledge of the maximum bearing temperature is a basic criterion of bearing, seal, or gear failure.

To make clear the kind of specific objectives assigned to the workshop, one can cite the following major needs:

(*a*) Much of the disarray prevailing in thermohydrodynamic (THD) lubrication is due to the large number of variables present.
(*b*) Many of the difficulties can be traced to lack of generality of the systems analyzed.
(*c*) Basic experiments are needed to answer a number of conceptual uncertainties.
(*d*) Much of the available data from THD tests is unsatisfactory because vital measurements cannot be made due to the lack of proper instrumentation. A case in point is measurement of temperature profiles across films only microns thick.

2.2 Organization. The working sessions of the Workshop consisted of an exchange of experience and ideas by participants from industry, academia, and government agencies, followed by critical discussions of the outstanding issues in the field. No formal papers were presented and participation was open to anyone interested in the subject of thermal problems in tribology.

The steering committee was composed of the following members:

W. O. Winer, Presiding Chairman
H. Heshmat, Organizing Chairman
F. F. Ling, and D. F. Hays.

The workshop consisted of a number of sessions, run consecutively, each lasting approximately one hour, with each session devoted to a specific subject within the scope of the workshop.

2.3 Contents. As stated, the framework of the workshop was confined to thermal problems in fluid film tribology. There were 12 sessions organized by topic, as listed in the Table below.

List of Workshop Sessions

Workshop Topics (Sessions)	Session Chairman
Rigid Films (THL)	A. Z. Szeri University of Pittsburgh
Mixing Temperatures	C. M. Ettles Rensselaer Polytechnic Institute

Time Varying Films	W. Gross University of New Mexico
Cavitation Phenomena	D. E. Brewe NASA Lewis Research Center
EHD	Harmen Blok University Delft, Netherlands
Two-Phase Flow Phenomena	W. F. Hughes Carnegie Mellon University
Turbulence	J. A. Tichy Rensselaer Polytechnic Institute
Experiments Needed	J. W. Kannel Battelle Memorial Institute
Instrumentation for Thermal Experiments	V. King Memory Tech. Group Lab 3M

Special Topics

At the end of the 3-day deliberations the participants were organized into four groups charged with the task of formulating conclusions and recommendations based on the preceding discussions and opinions voiced at the workshop.

3.0 Conclusions and Recommendations

3.1 Workshop Summation. At the end of the workshop the four groups submitted the following list of topics:

TOP PRIORITY

Thermohydrodynamic Lubrication
* Boundary conditions
* Effect of lubricant temperature on rotordynamics
* Shape of the temperature profile
* Start-up seizures
* Flat land seals

Turbulence
* Three dimensional equations for turbulence.
* Critical Reynolds and Taylor numbers.
* Simplified model for total stress.

Elastohydrodynamics
* Mechanism of heat dissipation
* Temperature distribution

Cavitation and Two-Phase Flow
* Mechanism of two-phase flow
* Physics of cavitation
* Contaminated/two-phase lubricant

Experiments and Instrumentation
* Techniques for measuring film temperature
* Heat transfer coefficients in fluid films
* Mechanism of film collapse in two-phase flow
* Mixing inlet temperatures
* Turbulence (two-directional measurements)

Second Priority

Thermohydrodynamic Lubrication
* Thermoelasticity
* Two-dimensional vs. three-dimensional results
* Cycling

Turbulence
* Heat transfer under laminar and turbulent conditions
* Experiments at high Reynolds numbers
* Turbulence models at Reynolds numbers greater than 10^5

Cavitation and Two-Phase Flow
* Film collapse phenomenon
* Temperature in the cavitation zone
* Cryogenics and two-phase flow

Experiments and Instrumentation
* Experimental stiffness and damping coefficients

In addition to the above, representatives of the Wright Aeronautical Labs of the U.S. Air Force stressed the following needs in the area of high temperature tribology.

* Solid lubricants
* Ceramic materials
* Non-metallic rolling element bearing
* Advanced piston ring studies
* Cycling operation studies
* Noise attenuation

3.2 Write-Up of the Workshop. The technical aspects of the workshop including its conclusions and recommendations are being written up by Oscar Pinkus in book form to be published by the ASME Press.

H. Heshmat
O. Pinkus