EPILOGUE TO THE NATO ASI ON FUNDAMENTALS OF FRICTION

1. Introduction

The NATO ASI at Braunlage was a fruitful exploration of the current state of knowledge and new approaches to friction processes (and other tribology-related matters). In addition to formal presentations, most of which are included in this book, the ASI devoted much of the last two days to discussing what areas of friction are well-understood and what issues need further clarification. The epilogue, divided into 5 parts, is a summary of those discussions as well as more recent inputs. The last day of the meeting was devoted to questions, answers and commentaries on "Future Issues in Friction at the Microscopic and Macroscopic Level." One of the commentaries, by David Tabor, nicely captures the atmosphere of the meeting and provides a clear and concise summary of many of the issues addressed. A transcribed version of his comments is given in part 2, below.

In preparation for the "Future Issues" session, the penultimate day was devoted to topical discussions. Eleven groups were organized, and each was asked to identify:
- What concepts of friction have been made clear on the macroscopic and microscopic level?
- What is missing (concepts, theoretical or experimental approaches)?
- What topics were not treated (fully) that need to be dealt with in the future?

Groups were kept smaller than fifteen, and participants were asked to wander from group to group and contribute to topics of interest. At the end of the session, the participants reconvened to hear 5-minute summaries (later transcribed and printed) from each group leader. The summaries and transcribed comments from the "Future Issues" session were distilled by the editors into a list of ISSUES and RECOMMENDATIONS. These lists (printed in bold letters), along with editorial comments and selected commentaries (in italics), are given in part 3. Two of the topics that generated much discussion, "Energy dissipation by friction processes" and "New ways of probing friction processes," are given extended attention.

Finally, everyone loved the molecular dynamic simulation videos of Uzi Landman, Jim Belak and Judith Harrison and the BBC science program with Thomas Mathia on "tribology of skiing." While there is no substitute for a good movie, a good diagram is sometimes second best. Lots of creative effort was spent generating diagrams depicting "Hierarchy of Friction Models" that span the microscopic to macroscopic. Three of these are presented in part 4. We end the epilogue in part 5 with the final comments of a lubrication engineer, Duncan Dowson, who wonders out loud how this knowledge of "microscopic friction processes" might influence engineers.

2. Commentary by David Tabor.

"This Conference I think has been for me the most exciting and worthwhile Conference on

Friction that I have ever attended. I have been greatly stimulated, and I think all of us have been, by the lectures, by the attention of the attendees, by the discussions, by the posters, by the participation of the audience as well as the lecturers and by the flexibility in approach shown by all our specialist participants. I would like to thank the organisers and the organising committee on my behalf and on behalf of all of you for arranging such a successful event.

The continuum approach. In attempting to assess major conclusions it seems to me that there is a consensus that continuum mechanics, contact mechanics and fluid mechanics will continue to supply the practicing engineer with the tools for designing and producing effective and viable machinery. But he or she will need to know more about the properties of materials and the properties of fluids, and this remains an ongoing problem for the tribologist. From the practical point of view bulk properties will be sufficient but when, for example, the EHL film reaches thicknesses of the order of a few hundred angstroms (as indicated by Duncan Dowson) we may have to consider in greater detail the molecular structure of the liquid. I shall refer to this later.

Surface topography. In this continuum approach to friction and lubrication we still have to struggle with the problem of surface topography. Probably the design engineer will continue to use the elegant profilometry techniques described twenty five years ago by Greenwood and Williamson - in spite of what Jim Greenwood tells us about some fundamental unresolved conceptual difficulties. I feel in the discussion of this issue like the happily married couple who after 25 years of married felicity suddenly learn that their marriage certificate is faulty and may be legally invalid. Nothing in their relationship is changed but they are not quite sure where they are. My impression is that engineering tribologists are well and truly wedded to the established ideas of surface profiles, distribution of asperity heights, radii of curvature of asperity tips and sampling distances. For the foreseeable future the old relationship will remain as a fundamental constituent of tribological design. It is up to those who have discovered a flaw in the marriage certificate to rectify the situation. I am sure we all wish Jim Greenwood and his colleagues every success in this serious task of preventing a divorce.

Energy dissipation. When we talk about friction we nearly always think of it as a force. It is very rare that workers talk of energy dissipation and when they do they refer to it in terms of bulk properties e.g. plastic flow, viscoelastic losses, viscous flow. And I think it is at this point that I notice a change in attitude at least amongst those who are interested in the mechanisms of friction. We are beginning to recognise that maybe we should be thinking of energy dissipation in terms of atomistic processes. For example the talk I gave here is not a lecture I took out of my file of lectures: it was one I had never delivered before because I had not been thinking specifically about energy dissipation, except in terms of bulk properties. It was stimulated by a questionnaire sent out by the Conference organisers. My approach seems very simple and obvious. I started with the friction of metals where it is known that plastic deformation usually occurs at the regions of real contact. We know that plastic deformation involves unstable displacements by unit atomic spacings along the slip plane, the atoms vibrating as they jump from one position to another. I came to see that all frictional processes - or most of them - involve a distortion of the atomic arrangement, an instability, a flicking back to a new position of equilibrium while the distorted material vibrates and the vibrations ultimately degrade into heat.

Of course with metals we may still think in terms of plastic deformation and simply assert that there is no problem here since it obviously involves the expenditure of energy. Similarly with viscoelastic solids we may explain energy loss in terms of springs and dashpots. But polymers are not made of springs and dashpots. They are made of molecules which in themselves have intrinsic elastic properties of rate-dependent modulus and they are impeded in their movement by