A Space Tribology Handbook

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The production of a Space Tribology Handbook forms part of an overall strategy, initiated by ESTEC's Mechanisms Section, to improve the quality of space mechanisms through the establishment of a set of globally applicable space mechanisms standards and guidelines for mechanism design. The standardisation activities are being performed under the European Cooperation for Space Standardisation (ECSS); the space mechanism engineering requirements have been established in an ESA/Industry collaborative effort in 1997. The Space Tribology Handbook provides the essential guideline for tribology aspects of mechanism engineering, useable in the day-to-day work of mechanism engineers. This strategy should promote a more standardised approach to mechanism design and testing and achieve reduced schedules, cost-effective developments and high-quality mechanisms.

The need for a Space Tribology Handbook

Tribology (from the Greek 'tribos' meaning 'to rub') is the study of friction, wear and lubrication. Friction and wear are generated at the interface of contacting bodies in relative motion and therefore occur in components such as bearings, gears, screws and slip-rings. If the friction (or adhesion) forces are high, a component may prove difficult to drive or, even worse, may seize; if high wear occurs, a component will lose its precision and, ultimately, its ability to operate at all. Tribology is, therefore, an important issue, especially in mechanisms intended for use on spacecraft – for if spacecraft mechanisms fail, there is (usually) no means to repair the damage or to apply fresh lubrication. Furthermore, if the mechanism in question is critical to the spacecraft's operation (as would be the case with solar array drives, antenna pointing mechanisms and deployment devices), then loss of the mission could result.

To avoid such anomalies and to ensure that mechanisms operate to their prescribed specification, effective designs are required which incorporate good tribological practice so that friction, adhesion and wear are minimised. In Europe, the importance of tribology in space was quickly recognised by the Agency and led, in 1972, to the establishment of ESTL (European Space Tribology Laboratory), which is now part of AEA Technology. Since then, ESTL has generated a considerable amount of tribological data, advised on tribological design issues, and tested tribo-components and mechanisms under space simulated conditions. As a consequence, a wealth of knowledge has been generated and much of this has been disseminated to the space community by way of publications and courses on space tribology. These activities have undoubtedly raised awareness of tribology and encouraged mechanism engineers to give due consideration to tribological issues in their designs. However, there was no handbook available detailing the tribological performance of materials and providing guidelines on their use in mechanisms design. It was for this reason that the Space Tribology Handbook was produced. With its publication, the space community now has a unique document which provides a source of information consolidated by test validation.

The Handbook has been written with the aim of assisting designers and engineers in the implementation of sound tribological practices and to help them determine how best to treat and lubricate components for a given application. Specifically, the Handbook:
– provides a definitive reference manual on space tribology
– provides useful data on typical systems where tribology is important either to performance or reliability
– specifies guidelines for the selection, use and limitations of tribo-materials (encompassing lubricants, surface treatments and substrate materials)
– aids the designer in the selection of tribo-components
– provides guidance on the ground testing of tribo-components and mechanisms.

Figure 1 shows the completed Handbook's cover with example sheets illustrating the format and style.

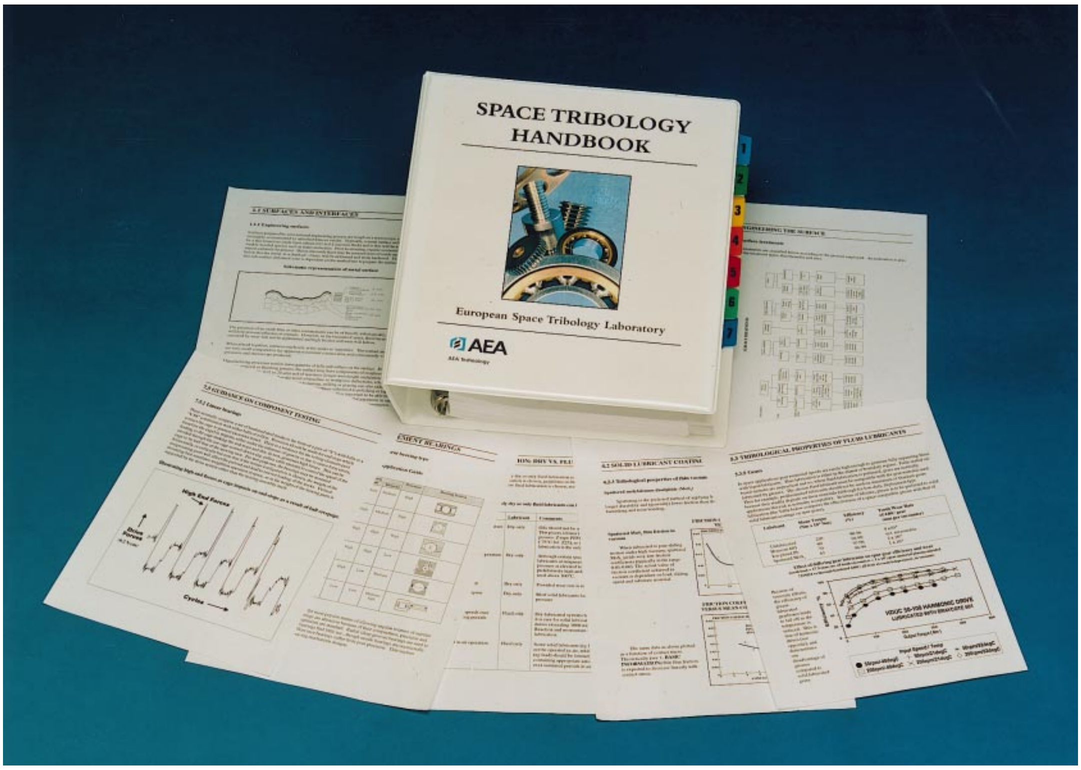

Figure 1. The Space Tribology Handbook showing examples of contents

The scope and structure of the Handbook
The handbook is arranged in seven chapters, the titles of which are listed in Figure 2. The first chapter serves as an introduction to tribology, its purpose being to familiarise readers who are new to the subject with the fundamental concepts of tribology. The remaining chapters form the Handbook's guidelines and span the progression from the initial selection of a tribological component, through its lubrication and, finally, to its testing at component and mechanism level.

A flow chart detailing how the various stages of component selection, lubrication and testing are presented and cross-referenced is illustrated in Figure 3.

Contents of Handbook
The following outlines the contents of the individual chapters of the Handbook.

Basic Tribology
Engineers involved in the design of mechanisms need to have an understanding of the basic concepts of tribology so that they can recognise the issues which are critical to the success, or failure, of their mechanism. Fundamental to this understanding is a knowledge of how engineering surfaces interact when brought into contact under load and how this interaction changes when there is relative motion (which may be separation, sliding or rolling) between the contacting bodies.

This chapter, therefore, looks at what happens when real surfaces come into contact and explains how contact areas in reality are small and contact stresses high. The manner in which surfaces deform is discussed and the conditions under which these deformations become permanent (plastic deformation) are

1. Basic Tribology
2. Tribo-component Selection, Design and Performance
3. Selection of Lubricant Type
4. Solid Lubricants
5. Fluid Lubricants
6. Materials for Tribological Components and Surfaces
7. Component and Mechanism Testing

Figure 2. Contents of the Space Tribology Handbook

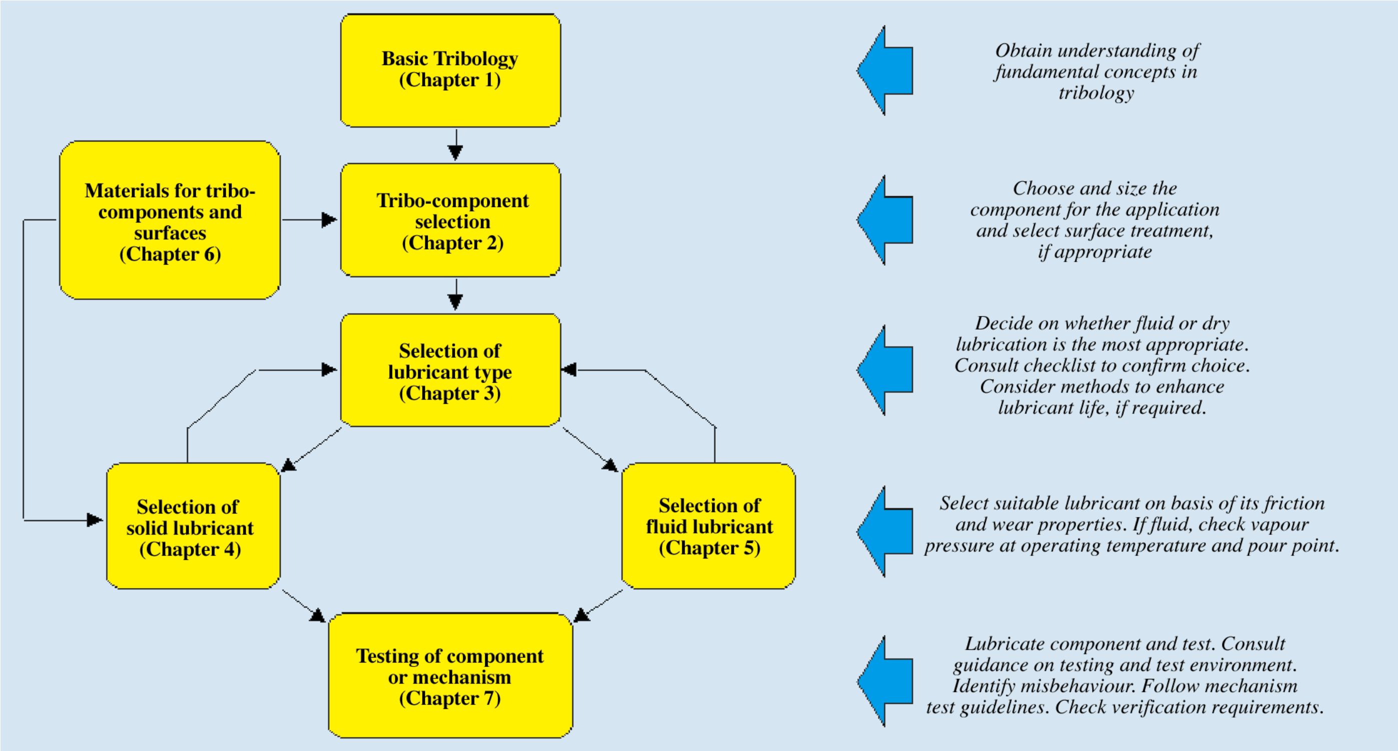

Figure 3. Flow-chart showing the Handbook's structure and logic

identified. The various phenomena, which give rise to friction and wear, are described and the manner by which these may be reduced (through lubrication) is explained. Finally the unique environment in which space mechanisms have to operate is defined and the impact such an environment has on tribological systems is outlined.

Tribo-component selection, design and performance

This chapter is intended to assist the designer in the selection of tribological components – that is, on how to choose the most suitable component for a given application (Fig. 4). The areas covered are:

- selection of rotary, rolling-element bearings
- selection of plain, spherical and rod-end bearings
- selection of ball, roller and plain screws
- selection of linear bearings
- selection of gears
- sliding electrical contacts
- other tribo-components: separation surfaces, end stops, cams, threaded fasteners, brakes, seals
- safety factor for tribo-components.

For each generic component, advice is given on which type of component is best suited to an application on the basis of parameters such as load capacity, stiffness and precision. The materials, and their relevant properties, from which the components are manufactured are specified. Examples are given of where specific components have been used successfully and what software is available to assist in design and prediction of performance.

Selection of lubricant type

Having identified the component to be employed, the next step to address is whether to use fluid or dry lubrication (Fig. 5). This chapter defines the criteria by which this decision should be made and also offers guidelines on selection for those cases where, in principle, both fluid and dry lubricants are applicable. Checklists are provided to help select a specific lubricant once the choice has been made between fluid and dry. In addition, suggestions are made on how to extend the life of space lubricants. The chapter features the following topics:

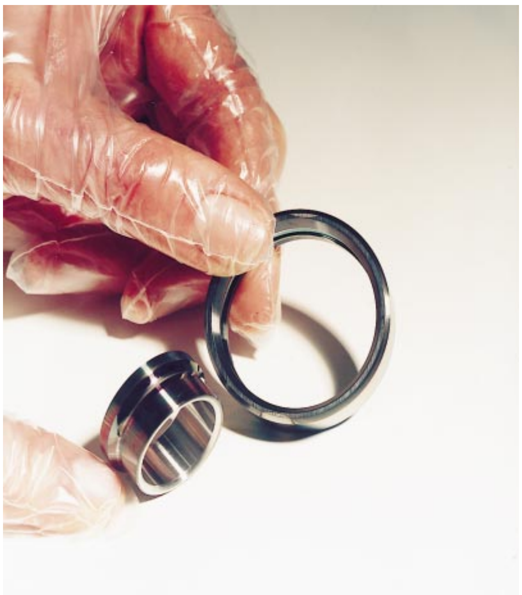

Figure 4. Effective mechanism design requires an informed approach to selection, sizing and lubrication of tribological components. The Handbook provides guidelines in these areas and helps to ensure that the most appropriate component and lubrication are chosen for a given application. The photograph shows a type of bearing (angular-contact) which is commonly used in space mechanisms. The races are lubricated with a thin film of molybdenum disulphide

Guide to selection; dry versus fluid lubrication:
- applications where only dry or fluid lubricants can be used
- choosing between fluid and dry lubrication when both are applicable
- checklist when choosing solid lubrication
- checklist when choosing fluid lubrication
- labyrinth seal leak-rate calculation.

Enhancing lubricant performance:
- extending life of perfluorinated lubricants
- extending life of solid lubricant coatings
- running-in of solid-lubricated components.

Figure 5. The choice of lubricant is critical to the successful operation of a space mechanism. The Handbook provides guidelines for selecting both fluid and dry lubricants. Specialised lubricant processes may be required such as the plasma-assisted deposition system, shown here, for the production of thin layers of lead films

Solid lubricants
Solid lubrication of a bearing may be brought about in one of two ways. It can be provided as bulk material for a moving surface, transferred by rubbing from a solid made from, or containing, the dry lubricant as, for example, with self-lubricating cages. Alternatively it can be applied to one (or both) counterface(s) in the form of a film, as with techniques such as sputter deposition. Information on both forms of solid lubricant is included in this chapter. The areas covered are:

Selection of solid lubricants:
- when to use solid lubricants
- advantages and disadvantages of solid lubrication
- types of solid lubricant.

Solid lubricant coatings:
- coating types and methods of application
- guide to selection of solid lubricant coatings
- tribological properties of thin films
- lubricant coatings for temperature extremes
- effect of environment
- coatings to prevent static adhesion and fretting damage
- storage and handling of coated components.

Bulk solid lubricants:
- polymers and polymer composites
- non-polymeric composites.

The section on coatings describes the various methods of application and the corresponding thickness ranges. This is followed by a general guide to selection based on the coatings' tribological properties in air and vacuum, their range of operating temperatures, their suitability for precision components, and the type of application and duty for which they are best suited. More detailed information on the tribological properties of specific coatings follows with examples of their performance when applied to ball bearings and gears.

The section on bulk solid lubricants deals with self-lubricating polymers and composites. The latter are composites containing solid lubricants, which may be reinforced with fillers in the form of particulates or fibres. The types covered are polymer composites (for bearing cages and gears), thin-layer polymeric composites (for journal and spherical bearings), metal/MoS_2 composites (for motor and slip-ring brushes) and leaded bronzes (for bearing cages). In each case the mechanical and material properties are specified and the friction and wear characteristics are listed.

Fluid lubricants
The following aspects are addressed:
- selection of a fluid lubricant
- fluid lubricant database
- tribological properties of fluid lubricants
- fluid loss, retention and replenishment
- handling, cleaning and lubrication procedure.

The section dealing with selection describes the types of fluid lubricant available and gives the relevant properties (vapour pressure and pour point) of some commonly used space oils and greases. More extensive data is provided by the fluid lubricant database which lists the known physicochemical and tribological properties of over 100 fluid lubricants that have been used, or are candidates, for space applications. The tribological properties of oils and greases are described and their measured performance in components such as bearings, gears and screws is presented.

Materials for tribological components and surfaces

This chapter surveys the properties of materials that have been used, or may be suitable for use, in tribological components in space mechanisms. Its purpose is to act as a reference source of basic material properties and as a supplementary source of information to that provided in other chapters. Additionally, a guide is given on the selection of base materials and appropriate surface treatments for commonly used tribological components. Specific topics covered are:

- the compatibility of materials with vacuum environments (vapour pressure and outgassing characteristics)
- physical and mechanical properties of bulk tribo-component materials (including hardness, elastic modulus, tensile strength, maximum operating temperatures and density)
- listings, descriptions and suitability of surface treatments
- a materials selection guide for bearings, gears, screws, fasteners and separating surfaces.

Component and mechanism testing

Here, guidance is given on the testing of tribo-components and mechanisms for space satellite applications. It identifies and defines the various test environments and provides guidelines on how to achieve them. Examples are given of thermal-vacuum test set-ups for component and mechanism testing together with notes on the testing of specific tribo-components (Fig. 6). The rationale for mechanism testing is explained and verification requirements, based on current ESA guidelines, are presented.

Future updates

In line with the evolution of space tribology, it is our intention to update the Handbook on a regular basis. This will be achieved by incorporating newly generated data and responding to the suggestions and reactions of users. In this way, the Handbook will remain a contemporary, up-to-date and, above all, relevant document which meets the needs of space mechanism designers and engineers.

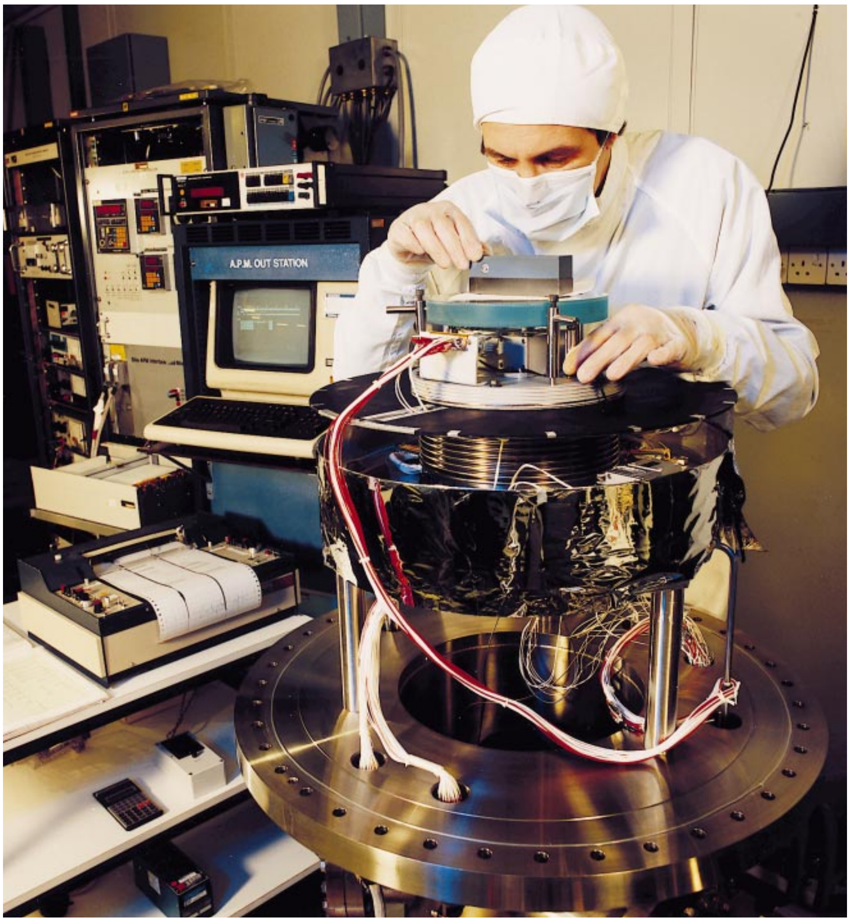

Figure 6. Thorough testing of components and mechanisms is essential in order to prove that all functional and lifetime requirements are met. The Handbook provides guidelines on all aspects of ground testing and details ESA's current mechanism verification requirements. The photograph shows the installation of an antenna-pointing mechanism in a test chamber where it will be subjected to a thermal-vacuum test

To obtain a copy of the Space Tribology Handbook, you can request an order form by writing to ESTL at the following address:

Space Tribology Handbook
ESTL
RD1/165
AEA Technology
Risley, Warrington
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WA3 6AT

Alternatively, telephone +44 (0)192525 3015 or send an e-mail to: emyr.roberts@aeat.co.uk

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