1973 Inspection of Lewis Research Center
September 19, 20, & 21

STOP 8 - "THE IMPACT OF WEAR"
Lubrication Branch
Fluid System Components Division

INTRODUCTION

Good morning (afternoon). I'm (Speaker #1). Welcome to our presentation "The Impact of Wear."

All of the presentations at this inspection show you the many benefits to mankind derived from the applied research and development work done here. This applied research and development work has as its basis the fundamental research, also performed here. It is this fundamental research that provides the working concepts required to advance this and any area of technology. This is probably the only Stop where examples of fundamental research will be discussed, as well as some applied research, where the benefits are more immediately apparent. Most of the equipment on display here is actual research hardware, used in our work, that has simply been moved onto stage for purpose of this inspection.

The need for lubrication in reducing wear was appreciated by primitive man. During the excavation of ancient tombs, archaeologists found animal tallow and other solids, used as axle lubricants. It is clear that without lubrication, the wheel would never have been a practical device. It would have been hard to turn, and it would have worn out in a comparatively short time.

The increasing complexity of man's labor-saving devices has been accompanied by more numerous and more difficult lubrication problems. To realize this, consider the transition from the chariot to the automobile or, over a shorter time span, from the Wright Brothers' airplane to a modern jet airliner.

Recent studies have indicated that the financial loss in the United States, due to inadequate lubrication, likely exceeds $10 billion per year. Certainly the "impact of wear" on mankind is extremely significant.

In the first part of this presentation, we will describe how wear occurs, and how some materials are better able to resist wear than others. The second part will be devoted to solid and liquid lubrication methods of solving the wear problem. Two examples of specific wear problems solved by using the knowledge gained from our fundamental research efforts will also be given. These examples imply that it may be possible to reduce the "impact of wear" on a large scale through fundamental and applied research efforts like our own.

II - WHAT WEAR LOOKS LIKE

The first step toward the solution of the wear problem is to understand how wear starts.

Wear starts with the condition of contact for two solid surfaces rubbing together under a load. As this slide (Slide # 1) shows, the contact is really between high spots, called "asperities," on each of the surfaces. A popular way of describing what the microscopic phenomena resembles is to say that the real contact of solids with normal engineering finishes corresponds to turning the Alps upside down and placing them on the Rocky Mountains.

In the next slide (Slide # 2), we see a metal surface with a lubricant film present on it. When the surfaces are loaded, the asperities must deform or yield until there is sufficient area to support the load. The lubricant film may be squeezed out and the bare metals will contact at various locations. Thus, it is possible, even if a lubricant is initially present on the surfaces, for areas of completely clean base materials to come into intimate contact. Under those conditions, practically all materials will adhere, or stick together at the junction points. Then, with sliding motion, those junctions, or the adjacent material, will break off. The sequence of adhesion and fracture of the junctions is a primary cause of the initiation of wear.

In recent years, surface analytical tools have become available that allow us to take "giant steps" toward a better understanding of the wear process. One of those tools is the scanning electron microscope, displayed here. Optical microscopes do not have the depth of focus to provide an adequate picture of the wear process. A friction and wear apparatus is built right into the instrument, providing for observation of the wear process as it takes place. Above the scanning electron microscope is a diagram showing the functional parts of the instrument. In the diagram you can see the electron optics and the arrangement of the specimens with respect to the electron beam. A stationary, hemispherically-tipped specimen is loaded against a flat, rotating disk, as shown (point out), simulating an asperity contact. That arrangement enables us to have a clear picture of wear, as it occurs, with magnifications up to 77,000 times. The best way of showing what we have observed is with a movie. In the movie, an iron hemisphere (39 thousandths of an inch in diameter) is sliding under load against an aluminum disk. At first you can see the generation of a wear track. Extensive wearing of the aluminum begins to occur as work-hardened particles of aluminum adhere to the iron, acting as abrasive cutting edges. This results in shear to the bulk aluminum, in a manner similar to metal cutting. Observe the aluminum "streamers" being sheared out of the bulk, much like chips coming off of a lathe.

Thus, we have two of the more common observations--adhesion, and abrasion, that define the wear problem. The question remains--how can wear be minimized?

III - WHAT CAN BE DONE ABOUT WEAR BY DESIGN OF NEW BEARING MATERIALS

In minimizing wear, we recognize that a protective film, or lubricant on the surface is always preferred; but in the event of lubricant failure, the base material itself should be able to reduce the damaging effects of friction and wear. One approach to this problem is based on atomic considerations. The arrangement of atoms, and the spacing between planes of atoms in crystals determine how metals deform, and the planes along which metals separate. We have models of two typical crystal systems, face centered cubic, and hexagonal close packed, mounted above this display.

The balls designate atoms and the sticks the spacing between atoms. The cardboard cutouts show the planes of atoms on which the atomic movements most likely occur during deformation, when forces are applied to the crystal. These planes are called "slip planes" and it turns out that the friction and wear properties of metals are highly dependent on these slip planes.

The next slide (Slide # 3), shows the relative wear of a metal in the cubic and hexagonal forms. Note that the wear of the cubic form is 100 times greater than that of the hexagonal. Further, the friction of the cubic form is several times that of the hexagonal form. Thus, a simple change of crystal structure in a bearing could make a household appliance, for example, last much longer. Also, these hexagonal materials are being considered for use in human artificial joints. This will be discussed later.

Another approach to improving the wear resistance of the base material is to add relatively small numbers of alloying atoms that tend to concentrate at the surface of the alloy, and possess beneficial friction and wear properties. The process of concentration at the surface is called "segregation." The basic structure of the bearing alloy can still be determined by bulk considerations; for example, mechanical strength and thermal conductivity, but the surface layer which dominates friction and wear process can be tailored to give a surface which significantly reduces friction, adhesion, and wear.

The next slide (Slide # 6), illustrates the segregation process in alloys. Heating or straining the surface, both of which occur during wear, causes the alloying atoms to move or diffuse. They tend to move or diffuse toward the free surface where they may influence friction and wear.

The diffusion process which is required for segregation to occur, can be readily demonstrated. Today we will show how gallium diffuses through aluminum such as this. Pure gallium is a liquid metal near room temperature. Turn your attention now to the TV monitors. Observe that a drop of gallium has been placed on top of a sheet of aluminum. In a short time, the gallium will diffuse through the solid aluminum and drop from the bottom of the sheet. In a similar manner, desirable atoms, from the standpoint of friction and wear, may be caused to move, or diffuse through the bulk metal and segregate at the surface.

The effectiveness of the segregation process in reducing friction may be demonstrated on this apparatus. Here we have commercially pure copper; 10% indium in copper; 10% tin in copper; and 10% aluminum in copper. The demonstration apparatus will show ribbon bars to indicate the coefficient of friction of the metal specimens loaded against a rotating steel shaft.

DEMONSTRATION

Observe that the 10% aluminum in copper shows the lowest friction. The 10% aluminum in the copper-aluminum alloy is sufficient to completely cover the alloy surface with aluminum by segregation. The concentration of aluminum on the alloy surface, operating in air, reduces adhesion between the alloy and the rotating steel shaft, thus lowering friction and wear. The surface segregation concepts provide an explanation of the observed behavior as well as letting us tailor-make new alloys with a wide variety of base metal.

In addition to using surface segregation to control friction and wear, the concept is being used by a major oil company in the search for low cost catalystic surfaces to reduce automobile exhaust emissions.

In addition to controlling the crystal structure, and segregating desirable atoms to the surface, there are other properties of materials that may be used to reduce adhesion, friction and wear. One of these is "texturing," which is the orientation of certain atomic planes parallel to the surface on which sliding occurs.

The next slide shows us what texturing is and how it develops in many materials systems. In more popular terminology, this is part of what might be called "run-in." For example, you all know it is commonly recommended that the initial operation of a motor such as that in an automobile be performed very carefully. You should not run at high speeds or high loads with new machine until it is run-in. One of the processes that occurs in run-in is texturing, as described on this slide.

Now, in the slide, we see a metal surface in which the grains initially have a random orientation. That is, the slip planes are randomly oriented with respect to the sliding surface (point out slip planes and sliding surface). We know the origin of wear particles begins with metal fracture along these slip planes; thus, in the case of a grain with the slip planes oriented at a steep angle to the sliding surface, the wear particles generated would tend to be large and if in a work-hardened state, would promote further wear by abrasion. This process was clearly observed in the movie. With careful run-in, a reorientation of the surface grains occurs. The slip planes near the sliding surface are no longer randomly oriented, but now have a preferred orientation parallel to the sliding surface (point out). This results in generally lower friction and smaller wear particles with reduced wear to the textured surface.

Thus far, we have discussed how wear occurs, and what can be done in the way of materials to reduce the impact of wear. Now (Speaker # 2) will discuss solid and liquid lubrication methods to reduce the impact of wear.

(SPEAKER # 2)

The purpose of lubrication is to separate the rubbing surfaces so that they are no longer in contact.

We will show you how this can be accomplished with both solid and liquid lubricants.

First, let us consider solid lubricants. You may be familiar with some of the common household solid lubricants like graphite and teflon.

This Center has pioneered the development of various solid lubricants for over three decades. The results of our studies are widely used in industry. Licenses have been granted so that industry can manufacture the patented lubrication materials we have developed here. Presently, one of our new lubrication concepts, which uses calcium fluoride, is being considered for new automotive engines like the Wankle engine and the gas turbine engine.

Materials which are good solid lubricants have a low shear strength. This simply means that they are naturally slippery.

To function properly, the solid lubricant must adhere to the surface that is being lubricated. How well this is achieved depends on the method that is used to apply the lubricant. We use a special method for applying solid lubricants. It is called "sputtering." It is performed in a vacuum chamber such as this one. The display above the apparatus will illustrate the sputtering process. The solid lubricant and the specimen to be coated are first placed in the chamber. The chamber is evacuated and then refilled with argon gas. This is represented by the yellow lights.

A negative charge is applied to the solid lubricant. This charge causes the argon atoms to ionize; that is, they lose an electron and become positively charged. This ionization process is represented by the yellow lights turning to blue. The blue glow you see in the vacuum chamber is the actual ionization process taking place. The positive argon ions are attracted to the solid lubricant and travel toward it at very high speed. The impact of these ions causes small particles of the lubricant to be expelled from its surface. Now, to coat a bearing surface we simply expose it to the bombardment of literally millions of these tiny lubricant particles. This process produces a very smooth, dense, but extremely thin solid lubricant film (typically, only 8 millionths of an inch thick). We have found that these thin sputtered films can lubricate better than conventionally applied films which are much thicker.

This sputtering process, as well as similar vacuum coating techniques, has very great industrial potential.

Their applications vary from wear preventive coatings in aircraft engines to protective coatings on razor blades.

Because of the industrial interest in this technology, we recently held a special conference so that we could convey this technology to industry.

Now, let's move on to the area of <u>liquid</u> lubrication. I will describe a particular type of lubrication which we are presently investigating.

The general features of this type of lubrication have only recently been understood. Consequently, its benefits to everyday machines have not been fully utilized.

An example of this type of lubrication can be found in an aircraft bearing such as this one. This ball bearing carries the thrust load of the main shaft of a jet engine.

The reliability and safety of an aircraft engine are highly dependent upon the lubrication of the balls within this bearing.

Let's look closely at the lubrication of one ball as it rolls over a bearing surface. To simulate this, we use a ball which rolls against a transparent sapphire disk. This is the arrangement we have in the experimental apparatus behind me. The actual region of contact is so small that it must be observed with a microscope. This camera will allow you to see what happens on the TV monitors. The load which is applied causes the surfaces to elastically deform and flatten out. The dark circular area you are looking at is where the ball and disk are actually in contact with one another. The actual size of this area is smaller than the head of a pin; and the maximum pressure between the two surfaces is nearly 200,000 psi which is similar to that found in aircraft bearings.

Before we start the surfaces in motion, let's look more closely at the lubrication process. This slide shows our microscope and bearing components which are fully immersed in oil. When the ball starts to rotate, the motion of the surfaces causes the lubricant to be dragged between them so that they actually become separated by a thin film of lubricant. This lubricant film is so thin that we must use the properties of light to measure its thickness. We do this by using interference fringes which are formed from the light which is reflected off both of the bearing surfaces.

The next slide will show you what we see through the microscope when the surfaces are in motion.

This is the region which has been elastically deformed under the high pressures.

The oil passes between the surfaces in this direction. As it leaves the high pressure region it breaks up or cavitates into tiny air bubbles.

The wavelength of the different colors of light tells us the thickness of the oil film. For example, the green color in the center corresponds to a surface separation of 20 millionths of an inch. The colors on the sides and at the rear indicate that the film is somewhat thinner at these locations.

Now, if you turn your attention to the TV monitors, we will demonstrate the generation of an oil film with our experimental apparatus. The black on white TV monitors show the interference fringes as dark and light rings around the region of contact. These fringes will move into the contact region when an oil film begins to separate the surfaces. When the bearing is rotated faster, the oil film becomes thicker.

An important lubricant concept that we are investigating is the effect of pressure on viscosity. As the lubricant passes between the surfaces, the high pressure causes the lubricant to become thicker (or more viscous). At bearing pressures of 200,000 psi, the oil in this region attains the consistency of tar. This tendency of a liquid lubricant to become solid-like at high pressures contributes greatly to its ability to separate highly loaded surfaces so that local adhesion and wear cannot occur.

The benefits of this type of lubrication are now being used to improve the performance of high speed aircraft bearings such as this one.

We have on display, over there, the latest design of this bearing. That bearing was tested for over 2500 hours at very high speeds and temperatures. This is the longest high-speed bearing test of its kind performed in the world. It was achieved by computer design of the bearing geometry and lubrication process. The improved performance of this bearing will allow more efficient and more reliable aircraft engines to be developed. In addition, bearing companies are already using these design and lubrication concepts to make better bearings for the benefit of everyday machines.

Now, let's consider the wearing parts in man's own body. Because of disease and injury, there are many people today with worn-out joints. The medical profession has requested our support to develop better artificial joints like the hip joint you see here and on the TV monitors. These artificial joints not only provide almost complete relief of pain, but they also allow a mobility that the recipients have not known for years. Over 100,000 such operations are performed each year.

This artificial hip joint consists of a metal ball which rides on a polyethylene plastic cup. The loads it must carry are very great. For example, normal walking can produce loads of up to 1000 lbs. With present day materials, the wear in this joint can become critical after only 10 years. Reoperation to replace it can in some cases be done, but it is not very desirable. There is a very urgent need to extend the wear life of artificial hip joints. This is why orthopedic surgeons have been very interested in our aerospace lubrication technology.

To study the wear processes in the artificial hip joint, we have developed a total hip simulator that you see here. This machine can simulate the complex loads and motions of human walking. The oscilloscope traces on the instrument rack show the variation of friction and load in the joint. We are using this machine to test the application of our aerospace lubrication technology.

Our research has shown that a thin film of plastic must transfer to the metal if low wear is to occur. The formation of this transfer film is influenced by the roughness of the metal surface. The next slide shows that there is a particular roughness value which corresponds to low wear. Presently used artificial hip joints have much smoother metal surfaces than this value. We feel that a proper surface roughness can greatly increase the life of an artificial hip joint.

In addition, there are perhaps better materials that can be used for the ball and cup. The commonly used material for the ball is a cobalt-chromium alloy which has a cubic crystal structure like this. As you may recall, the hexagonal metals like this one give lower wear. A better material for the cup may be a plastic called "polyimide." Our research has shown that this material has better bearing properties than the presently used polyethylene. These materials are now being tested in animals at the medical school of UCLA. These tests must continue for at least another year before a final decision on their use in humans can be made.

We have shown you some of our fundamental research as related to the impact of wear. Although it is difficult to estimate, we know that if this technology is properly used, it can substantially reduce the estimated 10 billion dollars that improper lubrication is costing this country each year.

SLIDE	TITLE
1	The Microscopic Nature of Metal Surfaces
2	Surface Films and Metal Contact Through Films
3	Effect of Crystal Structure in Cobalt on Friction and Wear
4	Elemental Segregation in Alloys
5	Texturing in Metals
6	Measuring Oil Film Thickness by the Wavelength of Light
7	(EHD Contact)
8	Effect of S.S. Surface Roughness on Wear of Polyethylene

Additional slides for the presentation were deleted because of limited time for presentation.

STOP 8   MAX SWIKERT 2142

CS 67592 1) THE MICROSCOPIC NATURE OF METAL SURFACES

CS 67593 2) SURFACE FILMS AND METAL CONTACT THRU FILMS

CS 67594 3) EFFECT OF CRYSTAL STRUCTURE IN COBALT ON FRICTION AND WEAR

CS 67595 4) ELEMENTAL SEGREGATION IN ALLOYS

CS 67596 5) TEXTURING IN METALS

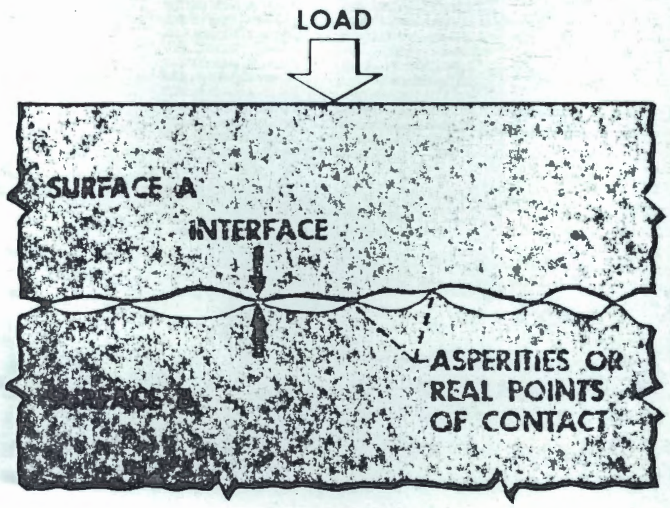
CS 67597 6) MEASURING OIL FILM THICKNESS BY WAVELENGTH OF LIGHT

CS 67598 7) ELASTOHYDRODYNAMIC LUBRICANT CONTACT

8) PHOTOMICROGRAPH OF PLASTIC PROSTHESIS CUP AFTER HIP SIMULATOR TEST WITH METAL BALL

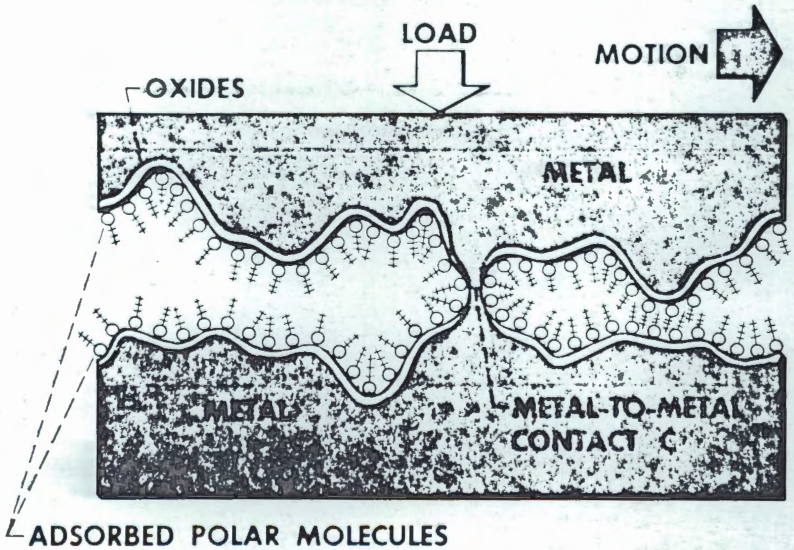
CS 67599 9) EFFECT OF STAINLESS STEEL SURFACE ROUGHNESS ON WEAR. . . OF POLYETHYLENE

THE MICROSCOPIC NATURE OF METAL SURFACES



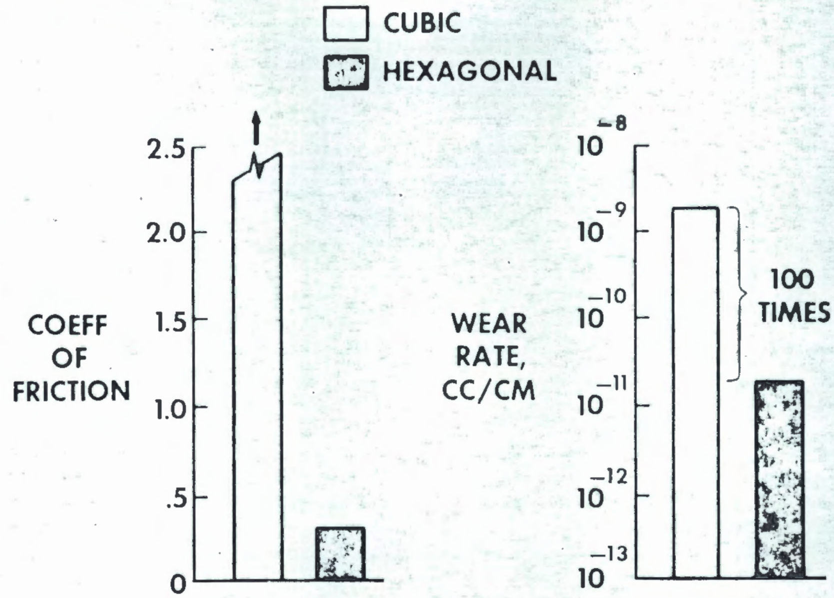
SLIDE 1 CS-67592

SURFACE FILMS AND METAL CONTACT THROUGH FILMS



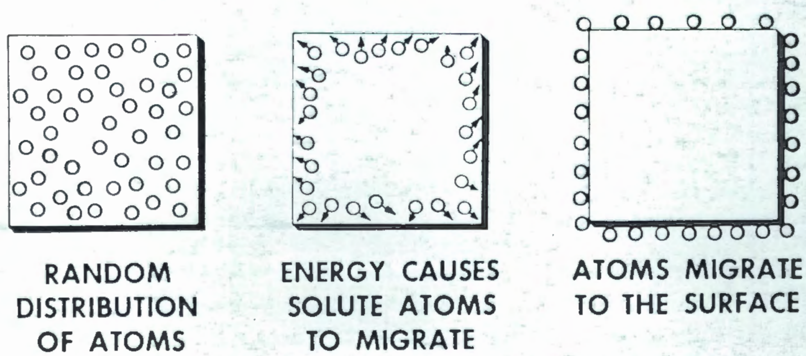
SLIDE 2 CS-67593

EFFECT OF CRYSTAL STRUCTURE IN COBALT ON FRICTION AND WEAR



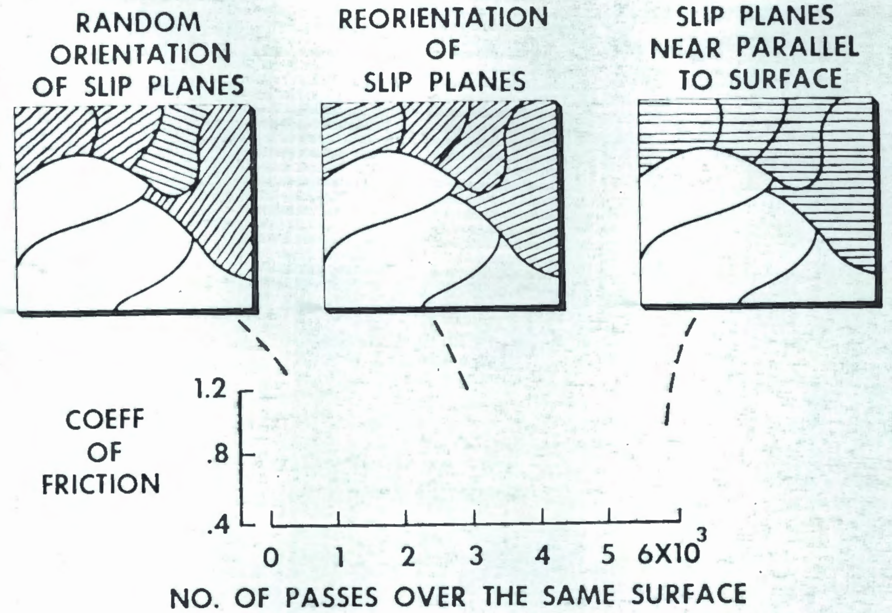
SLIDE 3 CS-67594

ELEMENTAL SEGREGATION IN ALLOYS



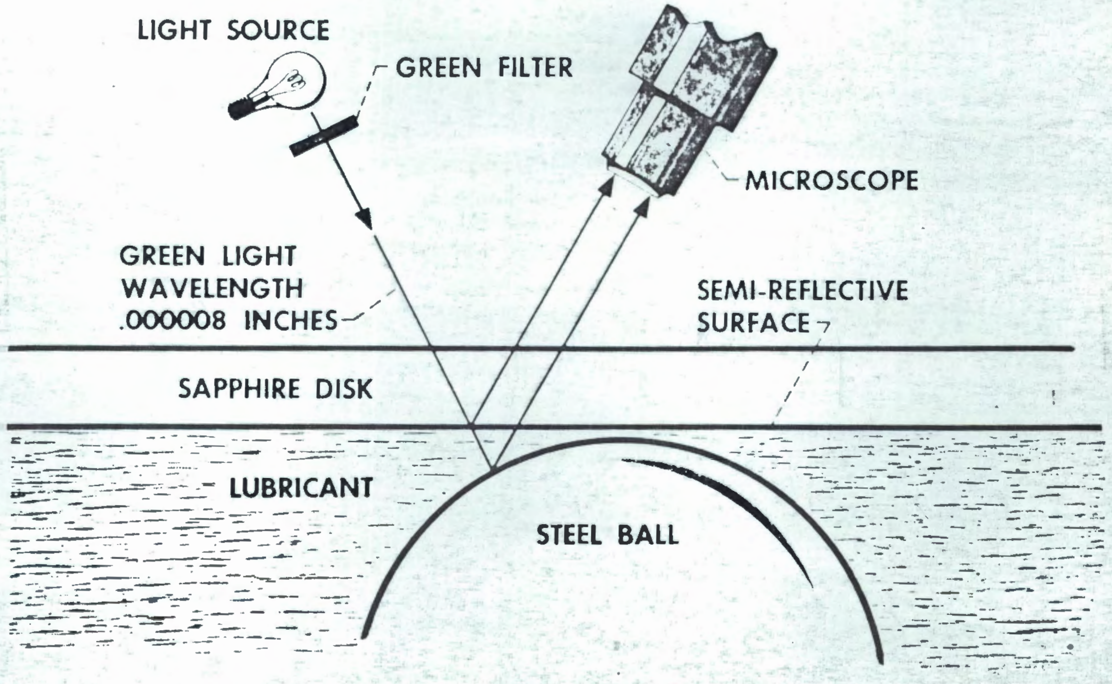
SLIDE 4 CS-67595

TEXTURING IN METALS



SLIDE 5 CS-67596

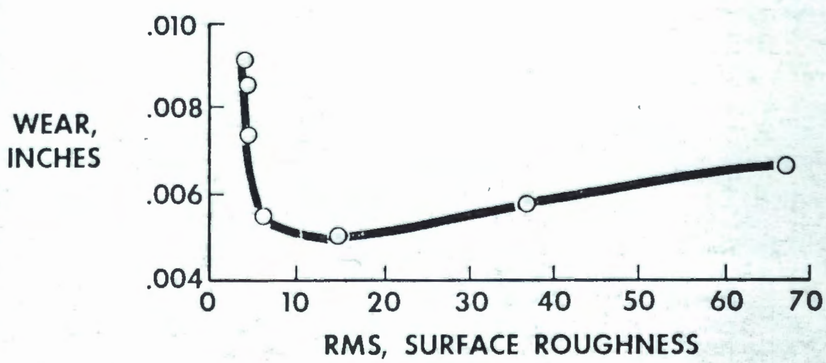
MEASURING OIL FILM THICKNESS BY THE WAVELENGTH OF LIGHT



SLIDE 6 CS-67597

SLIDE 7 CS-67598

EFFECT OF S.S. SURFACE ROUGHNESS
ON WEAR OF POLYETHYLENE



SLIDE 8 CS-67599

NASA
C-73-3412

NASA
C-73-3480