# Nasa Glenn Research Center — A Look Back

## Excerpted from *Tribology for Aerospace Applications*

Erwin V. Zaretsky

### NASA GLENN RESEARCH CENTER IS 75 THIS YEAR


In 1941, the federal Aircraft Engine Research Laboratory set up shop in Cleveland, Ohio. This year, and several name changes later, what is now the NASA Glenn Research Center celebrates its 75th anniversary. As part of the year-long festivities, Glenn's adjunct Lewis Field main campus will be open to the public May 21 and 22, and Plum Brook Station in Sandusky, Ohio will hold its open house June 11 and 12. There will be tours, and families can meet astronauts and talk with the center's scientists, engineers and technicians working on the nation's space and aeronautics programs. Admission is free, and space-themed souvenirs and NASA merchandise will be available for purchase. Watch for more details on the center's website (*www.nasa.gov/centers/glenn/events/tours*).

In an effort to recognize NASA Glenn's 75 years of invaluable research, *PTE* thought readers might find the following of particular interest. It is the preface from the 1997 book, *Tribology for Aerospace Applications*, co-authored and edited by Erwin V. Zaretsky of the Glenn Research Center, and in collaboration with his then-NASA Glenn contemporaries as well as with Society of Tribologists and Lubrication Engineers contributors. *Tribology for Aerospace Applications* is a textbook and reference source for designers of rotating machinery; users and designers of such mechanical components as bearings, gears, and seals; tribologists; university and industrial researchers; and students of machine design. The book incorporates information from more than 900 references, spanning over 50 years of technological advances. Copies of the book can be ordered from the Society of Tribologists and Lubrication Engineers (*www.stle.org*); Phone: (847) 825-5536.

But what makes the preface of this book of particular interest is that it serves as a concise but richly informative history of the center's early days—beginning with when winning a war was its vital, top priority. Once the peace was won, the real fun started. And when you see how much of the (largely unnoticed) U.S. space program R&D done by these men and women over the decades that has been successfully applied to commercial applications, you'll see it is one place where our tax dollars truly are "at work." **PTE**

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October 10, 1989. During dinner at the monthly meeting of the Cleveland contingent of the Society of Tribologists and Lubrication Engineers (STLE), Ed (Edmond E.) Bisson, a 1973 NASA retiree who decades previously had introduced tribology research at the National Advisory Committee for Aeronautics (today's NASA), turns to Bill (William I.) Anderson and in his best reminiscing voice begins recalling his years of tribology research at the Lewis Research Center. There, until 1984, more than 35 research scientists and engineers were dedicated to identifying and advancing the state-of-the-art in lubrication, bearings, gears, friction, and wear.

Don (Donald H.) Buckley stops Bisson to interject: "The decision to cut back this research came from NASA headquarters, but tribology research is still being conducted at Lewis in the Surface Science Branch of the Materials Division," referring to the re-named group he had headed prior to his own retirement from the agency.

Anderson, joining the conversation, remarks to Buckley, "That's true, but areas of technology that might have been previously addressed are not now being adequately covered as a result of those 1984 cutbacks."

Bisson asks (declaring, really), "Like work on space mechanisms for long-term space missions, dynamic and static sealing, highly reliable, long-term cryogenic turbo machinery bearings, and bearings for advanced aircraft?"

"Precisely," Anderson responds. "In fact, the bearing technology that is operating in the space shuttle turbopumps today is what we developed at Lewis in the early-to-mid-1960s."

Until this point I sat listening, eating my meal. The conversation sounded

# THE PROTECTOR

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OUR PRELOADED BALL-DETENT SAFETY COUPLINGS.

like many we had over the years at Lewis when Bisson, Anderson, and Bob (Robert L.) Johnson managed all of tribology research at the Center.

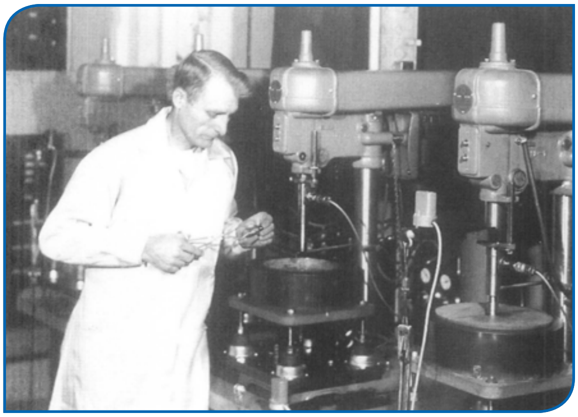
So I turn to Bisson, "You know, Ed, you never told me just how you got started in tribology."

Bisson sits back and jokingly answers, "I'm glad you asked," with a detectable 'What took you so long?' tone in his voice.

"The group's origin was actually in 1939, at the NACA (National Advisory Committee for Aeronautics) Langley Field Laboratory in Virginia in the Power Plants Division," he says. "At that time and during World War II our primary concern was the lubrication and wear of piston rings and cylinder barrels in reciprocating engines. In 1943 we moved from Langley Field to the NACA Aircraft Engine Research Laboratory in Cleveland, Ohio.

"(At that time) the U.S. Army Air Corps (now USAF) was flying aircraft from unimproved air fields. In North Africa particularly, aircraft were taking off in a virtual sandstorm. Ingestion of sand played havoc with rings and cylinders, wearing them badly. Overhauling these engines could be simplified appreciably if the overhaul shops could stock standard-size pistons and rings, rather than several different sizes (over-sizes) of pistons and rings.

"Such stock simplification necessitated that the cylinder barrels be of standard size. Experiments were conducted to establish whether worn cylinders could be electroplated with chromium — back to standard size — without adversely affecting their lubrication and wear properties. There are two types of chromium plate: dense and interrupted. Dense chromium plate did not have good friction and wear properties, but interrupted chromium plate did. The interrupted surface plating was obtained by reversing polarity as the plating process was coming to an end.



Eldred Johnson, chief technician for bearing research at NASA Lewis, with NASA five-ball fatigue testers on January 20, 1960. The fatigue tester was conceived by William Anderson, designed by Thomas Carter and Erwin Zaretsky, and assembled and operated by Johnson. The first tester began operation in March 1959. Eight testers were built by NASA. Over one-half-million test hours had been accumulated and reported before NASA terminated the research in October 1964. (All historical photos courtesy STLE.)

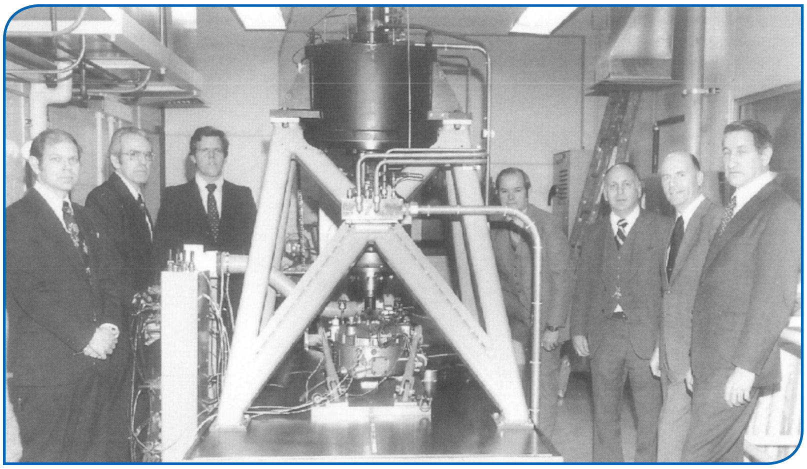
"Research was also conducted on nitrided-steel piston rings in an attempt to extend the wear life of the rings. Although extremely difficult, design and construction of nitrided piston rings were accomplished and research toward incorporating steel piston rings was continuing as the war ended in 1945. Single-cylinder engine tests at NACA Langley were used to check friction and wear of chromium-plated cylinders, as well as of nitrided-steel piston rings. Full-scale engine tests were conducted by other U.S. agencies under NACA direction."

Buckley queries Bisson: "Who were the key people performing this work?"

"Myself and Bob Johnson," Bissson replies. "At the end of World War II, NACA's interests shifted to the turbine engine with its accompanying problems of high-speed, rolling-element bearings, high-speed seals, and higher-temperature synthetic lubricants. It became evident that scientific research was necessary on the fundamentals of friction, lubrication and wear. We carried out basic tribology studies on 'mechanically clean' surfaces of various materials. Because turbine engines needed lubricants with high-temperature capabilities, we studied synthetic liquid lubricants and solid lubricants with higher temperature capabilities than the mineral oil lubricants then available."

Buckley adds, "The solid lubrication studies were interesting in that the group began to examine the fundamental lubricating properties of what was then a new lubricating material — molybdenum disulfide ($MoS_2$). Considerable research on the other then-principal inorganic solid lubricant — graphite — was well under way by this group and elsewhere.

"There was little difficulty in justifying the study of solid lubricants because early in (the war) a very serious problem developed in military aircraft. When they (would fly) at high altitudes to minimize detection and assault vulnerability, the carbon brushes of the



Visit by staff members of Bell Helicopter in 1979 to recently inaugurated NASA Lewis 500-hp helicopter transmission test stand. Left to right: Dr. John Coy (NASA), Charles Braddock (Bell), Stuart Loewenthal (NASA), B.J. Hampton (Bell), Erwin Zaretsky (NASA), Walter Sonneborn (Bell), and Dennis Townsend (NASA). The work by NASA on the Bell OH-58 transmission improved life and reliability and increased power-to-weight ratio by approximately 50 percent.

aircraft generators began to exhibit a severe wear problem that came to be known as 'dusting.' The carbon brush manufacturers, NACA, and others undertook to find a solution to the dusting problem. As is so often the case, this critical need was the impetus for beginning fundamental solid lubrication studies in earnest. The role of graphite content in carbons and the effect of environment on graphite behavior were extensively studied, as was the role of adjuvants (materials added to carbon bodies to blunt their environmental sensitivity). Much of this work was published in NACA technical notes shortly after the war and was nicely summarized some years later by Bisson and Anderson (in their 1964 book, *Advanced Bearing Technology*). This latter summary was particularly significant because at the time it was prepared, NASA was in a race to develop lubricants for space applications and much of the fundamental understanding gained during the war served as the guiding light."

"Molybdenum disulfide during World War II was pretty much still a laboratory curiosity," Buckley continues. "Some of the first attempts to use it as a solid-film lubricant were made at NACA. I vividly recall seeing vials of corn syrup in the laboratory and upon inquiry being advised that this was the mechanism for achieving adhesion of molybdenum disulfide to substrates to be lubricated. Since those early beginnings, hundreds of papers have been written by authors the world over on the solid lubricant molybdenum disulfide and how to achieve its adhesion to surfaces."

**Left to right: Erwin Zaretsky (NASA), Dr. Romaldus Kasuba (Northern Illinois University), and John Coy (NASA). A visit to NASA Lewis in January 1995 by Kasuba, Dean of Engineering at Northern Illinois University and an internationally known gear expert.**

Anderson offers, "Actually, the jet engine probably was the greatest technology driver in the field of tribology. I remember that when I began working at Lewis in 1951, rolling-element bearing life in jet engines was approximately 300 hours. The bearings were probably the single greatest inhibitor of jet engine reliability and maintainability. Major advances in rolling-element bearing technology were needed so that engine designers could fully utilize advances in engine aerodynamics and thermodynamics. Engine designers were projecting needs for bearings capable of highly reliable, long-life performance at *DN* values exceeding 2 million and operating temperatures exceeding 400°F. Among the perceived research needs were improvements in bearing design, lubrication techniques, lubricant-limiting temperatures and materials."

Bisson adds that "If I remember, the bearing group besides you initially included Fred Macks and Zoltan Nemeth, to be joined later by Bob (Robert) Butler, Tom (Thomas L.) Carter, Fred (Frederick) Schuller, Bob (Robert) Cunningham and Erv (Erwin V.) Zaretsky. In 1958, (NASA) was organized with former NACA installations such as the Lewis Flight Propulsion Laboratory (renamed in 1948), serving as the core facilities of the new agency. The NASA Lewis Research Center was born and quickly assigned primary responsibility for air-breathing and space propulsion systems and space auxiliary power systems. These broadened responsibilities required a significant increase in the scope of research. It became impossible to do all of the required work in-house — even with a rapidly expanding staff. University grants and contracts with aerospace companies became a prominent segment of the total R&D activity at Lewis. Organizational units with primary responsibility for contract management were formed. Members of in-house research groups served as technical advisors and monitors on contractual R&D. The original bearings group became, successively, the Bearing Section (as part of the Lubrication and Wear Branch), the Bearing Branch, and finally, the Mechanical Components Branch. The last name reflected the broad expansion of research efforts that grew to include fluid film bearings (organic liquid, gas, and liquid metal lubricated), rotor dynamics, gears, and transmissions.

**Visitors to NASA Lewis in 1974 to discuss NASA gear research results. Seated, left to right): Dr. Hillel Poritsky (General Electric), Dr. Harmon Blok (Delft University, Holland), and Dr. Lee Akin (GE). Standing, (left-to-right): Dr. John Coy (NASA), Erwin Zaretsky (NASA), and Dennis Townsend (NASA). Poritsky, during his career at GE, was a pioneer in fluid film lubrication and contact mechanics. Sick, who performed gear-related pioneering lubrication research, is famous for his "flash temperature" theory. Akin had a long, cooperative relationship with NASA Lewis, performing pioneering gear lubrication studies with Townsend.**

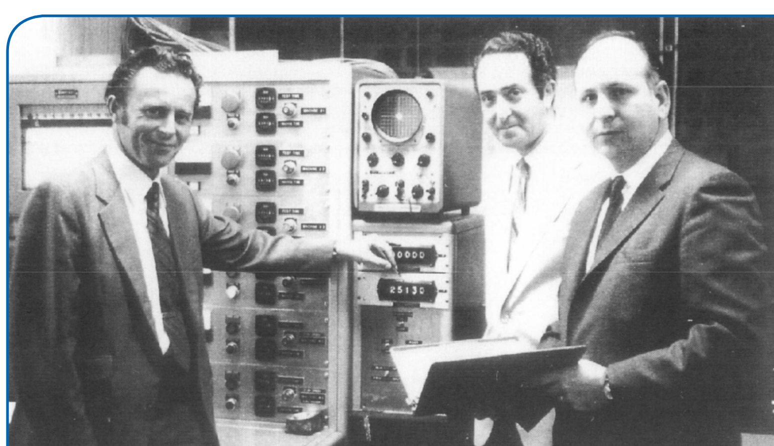
"Using sophisticated surface analytic equipment," Bisson continues, "much basic information was obtained by Bob Johnson's group on the effectiveness of various contaminants (such as absorbed gases and hydrocarbons) in reducing adhesion and friction of clean surfaces. As I remember, the results showed that even partial coverage of the surfaces by gaseous oxygen, hydrogen sulfide, or various hydrocarbons can be beneficial. In fact, as little as one-quarter or one-third of a monolayer coverage can reduce adhesion and friction appreciably."

Buckley is nodding in agreement as I ask him, "Who besides you and Bob Johnson were involved in that effort?"

"K. (Kazuhisa) Miyoshi and 'Tally' (Talivaldis) Spalvins on lubrication fundamentals, and Hal (Harold E.) Sliney on high-temperature lubrication."

Anderson offers that "The broadened scope of research was accompanied by a significant growth in personnel complement. New staff members included Neil Anderson, Dave (David E.) Brewe, Harold H. Coe, John Coy, Marshall W. Dietrich, George K. Fisher, Dave (David P.) Fleming, Bernie (Bernard H.) Harnmick, Al (Albert F.) Kascak, Stu (Stuart H.) Linewentlaal, Andy (Andrew) Mitchell, Dick (Richard I.) Parker, Dave (David W.) Reichard, Doug (Douglas A.) Rohn, and Dennis P. Townsend. The unique talents and dedication of this group made possible a broad array of advances in the state of the art in bearings, gears, lubrication, transmissions, and supercritical shafting."

"As an organization," I respond, "we probably did more research on rolling-element fatigue than any other single group worldwide. The NACA spin rig, which was conceived by (Macks) in 1953 and put online by Tom (Thomas L.) Carter in 1955, produced the first large quantity of data on rolling-ele-



**Left to right: Hans Signer (ITO, Eric Bamberger (GE), and Erwin Zaretsky (NASA). Working together as a team under NASA sponsorship, these three designed and operated the first successful 3-million-DN bearings at Industrial Tectonics, Inc., Rancho Dominguez, California, on June 29, 1973. The photograph was taken in the control room after the two specially designed 120-mm-bore ball bearings had reached a speed of 25 130 rpm and 425 F. After 2,500 test hours, the bearings were removed undamaged.**

ment fatigue used to evaluate materials, lubricants, temperature, and stress effects on bearing life and reliability. Limitations of the spin rig as a test vehicle for conducting fatigue tests at elevated temperature resulted in Anderson conceiving the NASA five-ball fatigue tester in 1958."

Anderson breaks in to graciously add, "Of course, if you and (Carter) had not designed and built the five-ball rig, it would have never been a reality. The spin rig and the five-ball fatigue tester produced a great deal of valuable data on rolling-element fatigue. Much of what we know today regarding the parameters that influence rolling-element fatigue evolved from tests conducted in these two invaluable testers. They greatly reduced the need for much more costly and time-consuming, full-scale bearing tests."

I remind that "From 1959 to 1985, as a result of these test rigs, we were able to increase rolling-element fatigue life by nearly 40 times what was benchmarked in 1958."

"This was quite an accomplishment," says Bisson. "In practical terms, rolling-element reliability in jet engines today can exceed 60,000 hours, with a potential of over 100,000 hours before replacement. Sure beats the 300 hours of the early 1950s!"

Buckley points out that the work on dynamic seal technology paralleled the accomplishments in rolling-element fatigue and bearing technology. "Seal speed capability went up approximately 50 percent as a result of our research, with a significant reduction in gas leakage." To which Bisson adds, "I don't want to brag — but I will anyway. As a result of our improved seal technology, the engine companies achieved greater engine efficiency and reduced fuel consumption for the airline industry."

"(I believe)," says Buckley, "that the researchers in the seal group were Larry (Lawrence) Ludwig, Gordy (Gordon) Allen, Bill (William) Hady and John Zak."

"We also made a significant impact on gear and mechanical power transmission technology," I say. "We were late starters in 1969, but we filled a much needed gap in technology. I remember starting to advocate this program in 1965; it took me nearly four years to get approval. With the addition of Dennis Townsend, John Coy, Stu Loewenthal, and Neil Anderson, we were able to make significant contributions in gear fatigue, life prediction, and reliability. The first practical gear rig to study tooth pitting and gear lubrication was designed and built by Townsend. Loewenthal and Anderson did pioneering work on gear and transmission efficiency, as well as on traction drives. Much of our lubrication and bearing work carried over to our gear research."

To which Anderson adds, "The impact of this work was on both U.S. Army and civilian helicopters, as well as on turboprop aircraft and wind turbines. You and the group were able not only to create a significant database and design analysis, but also to demonstrate increased helicopter transmission survivability with oil out. The application of the NASA/Lewis technology in the Helicopter Transmission System Technology Program from 1977 to 1984 demonstrated a 50 percent increase in power-to-weight ratio, with no reduction in transmission life, reliability or efficiency."

Bisson: "Since I started all of this, as well as this conversation, I should be able to summarize our other significant accomplishments. Bill, take notes, I may not be able to remember this again."

Bisson turns to Buckley and me and with a smile says, "Help me and Bill out" (*see sidebar*).

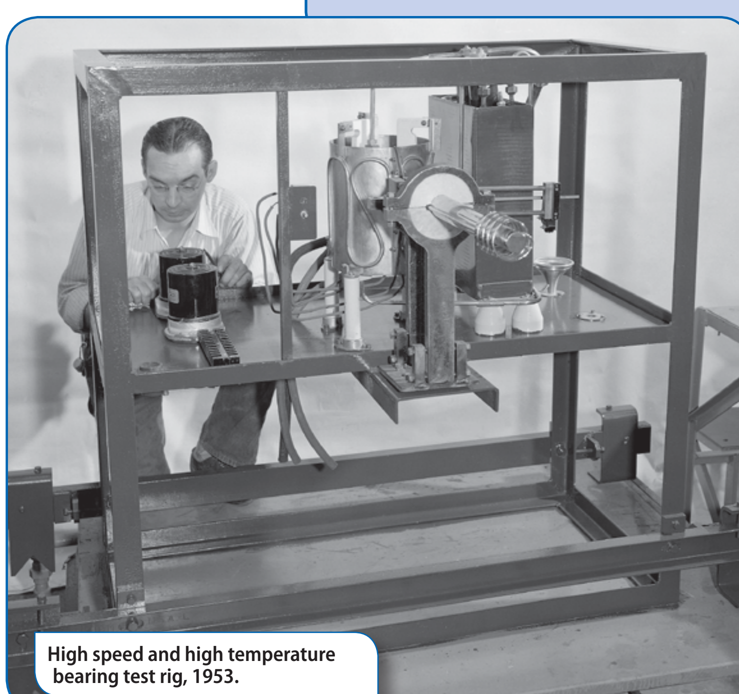
Bill, looking over the list says, "Do you realize that this list represents nearly 50 years of tribology research at Lewis? Someone should put all this material into a book."

"Sure," I jokingly — I thought — say — "*Tribology in Aerospace Applications* would be a good title." **PTE**

## 50 YEARS of TRIBOLOGY RESEARCH AT NASA GLENN

### Aircraft Turbine Engine Rolling-Element Bearings

- First test of turbine engine main-shaft bearing made of high-temperature tool steels
- First successful 3-million-*DN* ball bearings
- First data showing the relationship of elastohydrodynamic (EHD) film thickness, lubricant type, and rolling-element fatigue
- First analytical formulation and experimental verification of residual and hoop stresses on bearing life
- Analytical formulation of EHD lubrication film thickness
- Improved rolling-element bearing cage designs
- Improved rolling-element bearing lubrication techniques
- Improved rolling-element bearing materials
- Improved analyses for rolling-element bearing life, power loss, and temperature rise
- Increase in bearing operating temperature to 425° F in air and 600° F in low-oxygen environment



High speed and high temperature bearing test rig, 1953.

**High-Energy Rocket Engine Turbo-Pump Bearings**

- Successful operation of ball bearings with self-lubrication cages at high *DN* values in both liquid oxygen and liquid hydrogen

**Rankine-Cycle Space Electric Power System Bearings**

- Successful operation in sodium potassium (NaK) of anti-whirl journal bearing designs with definition of stability limits

**Brayton-Cycle Space Electric Power System Bearings**

- Analytical formulations for design of gas-lubricated tilting pad, Rayleigh step, and spiral-groove journal and thrust bearings
- Super-Critical Shafting
- Analytical formulations of both influence coefficient and modal balancing
- Analytical formulations for determining resonant speeds and mode shapes for both undamped and damped shafting
- Improved dampers for high-speed shafting

**Gears**

- Improved materials
- Improved high-speed lubrication techniques
- Modified tooth forms for improved life and lower noise
- Analytical formulations for life and power loss prediction

**Seals**

- Analytical formulations of Rayleigh step and spiral-groove life pad seal characteristics
- Pressure-balanced seal design
- Zero-leakage seal designs

**Transmissions**

- Design and experimental verification of fixed-ratio multi-roller planetary traction drive
- Higher power-to-weight-ratio hybrid (gear/traction roller) transmissions for helicopters
- Higher power-to-weight-ratio multipath gear transmissions for helicopters
- Higher power-to-weight-ratio standard geared helicopter transmissions through advanced bearing, gear, and lubrication technology **PTE**

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