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COVER

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About the cover
Flight loads imposed on aircraft structures and fasteners over time can cause cracks that threaten structural integrity.

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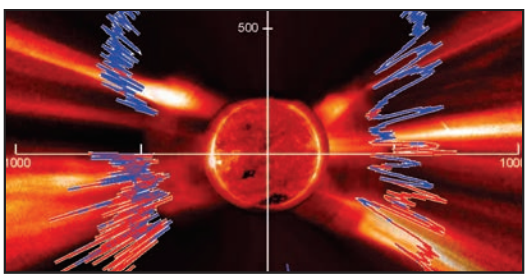

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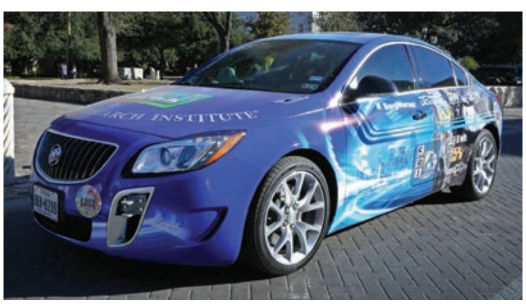

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Keeping U.S. Military Aircraft Flightworthy

SwRI support of U.S. Air Force Aircraft Structural Integrity Program spans more than three decades

By Kenneth Griffin, Ph.D.

Ensuring the fleet of U.S. military aircraft remains operational, and, more important, flightworthy, is a crucial component of our nation's defense system. Understanding and maintaining the structural integrity of the airframes are critical to extending the lifespan to keep these aircraft flying.

The U.S. Air Force's Aircraft Structural Integrity Program, or ASIP, provides engineering support throughout the lifetime of its aircraft, from design and testing to operational use and eventual retirement. The program was developed as a result of airframe structural failures surprising the Air Force during the Cold War, threatening the use of the medium-range B-47 strategic bomber. A concerted effort was made to fashion a structural life management methodology for military aircraft from data collected through a range of tasks, from full-scale fatigue tests to material characterization studies. The program has evolved to include the entire airframe lifecycle for all U.S. Air Force aircraft and has been refined into the guidance known as Military Standard 1530C, Aircraft Structural Integrity Program.

Southwest Research Institute (SwRI) engineers are an integral part of the ASIP program for the T-38 twin-jet trainer aircraft and the A-10 Thunderbolt II, both at SwRI headquarters in San Antonio and at the Ogden Air Logistics Center (ALC) at Hill Air Force Base, Utah, where SwRI engineers work alongside their Air Force structural engineering counterparts. SwRI has been involved in the T-38 program since the early 1980s and the A-10 since the late 1990s. Over the years, SwRI researchers also have performed work concerned with the primary airframe structure for a number of other Air Force aircraft, including the T-37, F-5, C-130, C-141, F-16, C-5 and others.

At present, engineers are conducting life analyses and full-scale testing on T-38 wings in a facility at SwRI's headquarters and life analyses of the A-10 on-site at the Ogden ALC. This work is led by the Aerospace Structures Section of SwRI's Mechanical Engineering Division and supported by researchers in the Division's Materials Engineering Department and Sensor Systems and Nondestructive Evaluation Technology Department.

SwRI's role in ASIP

While SwRI engineers have, in some cases, been involved from the early development stages of new aircraft, their primary workload in support of ASIP is geared toward sustaining the health of an aircraft's structure during its operational lifetime, with metal fatigue being

Dr. Kenneth Griffin stands in front of an SwRI-designed-and-built test frame in which an entire aircraft is suspended for testing. Griffin is manager of the Aerospace Structures Section in SwRI's Mechanical Engineering Division. An aerospace engineer, he has 43 years of experience in research, development, test and evaluation of aircraft structures, including serving as chief of the Structures Division of the Air Vehicles Directorate, U.S. Air Force Research Laboratory.

of primary concern. This entails characterizing the loads an aircraft generates during flight and using these loads in an array of analyses to predict structural fatigue. SwRI researchers conduct inspections and tests to confirm these structural life projections are valid for the primary structure of the aircraft.

Assessing structural life

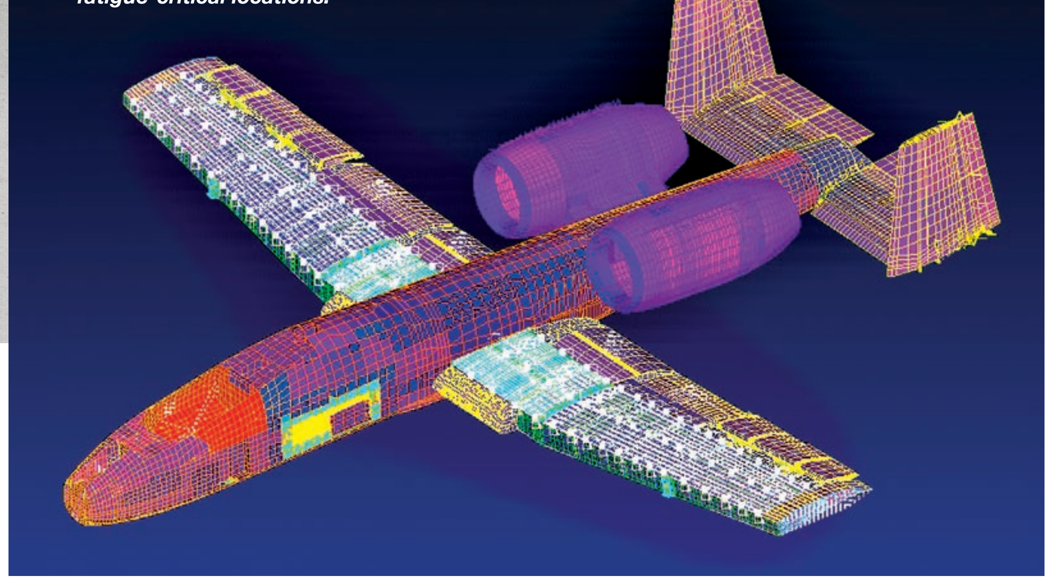
An essential ingredient in the ASIP effort is to ensure predicted loads — the forces an aircraft is subjected to — are correct and representative of current and expected use. Structural load data sets for all aircraft operations are developed during wind tunnel testing and flight-test development of new aircraft. These external loads can be categorized as functions of aircraft maneuvers, speeds, altitudes, and gross weights, among others. Using these structural loads, structural life calculations can be developed from information about the aircraft's mission(s) and the way it is being flown. The aircraft's use must be understood and kept current to ensure structural life projections are correct.

To collect this valuable information, data recorders are installed on a number of aircraft in the operating fleet. A variety of SwRI-designed, built and installed recorders are used for the T-38A and T-38B models. On other aircraft, such as the A-10, usage recording for structural assessments is achieved as part of digital records made for other systems, such as engines, internal systems and avionics. The A-10 recorders that monitor engine performance and maneuvers during flight and are used to calculate structural loads were developed by engineers in SwRI's Aerospace Electronics, Systems Engineering and Training Division. SwRI engineers interpret these recordings into flight usage histories that are the basis for the analytical studies necessary for structural life projections.

These results are interpreted both manually and through SwRI-developed computer-automated procedures. There are multiple steps to catalog and organize this information into load sequences, or spectra, used for structural fatigue analyses. Statistical guidelines and engineering judgment also are often needed to reconcile unexpected recorded events to ensure the fatigue results are useful to determine the need for inspection, repair or replacement.

What is metal fatigue?

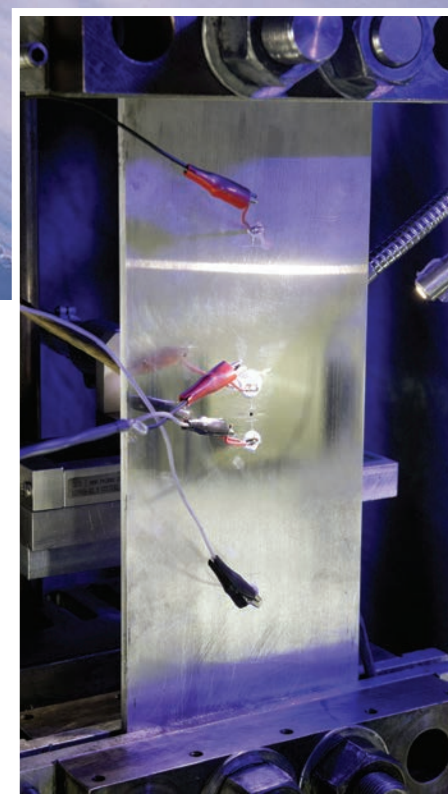
Areas of concern in an aircraft structure typically are defined as the aircraft is put through initial ground and flight testing, often guided by the structural analyses that were used in designing it. These locations, called hot spots, fatigue-critical locations (FCLs) or structural control points, are the focus of structural life calculations, inspections and maintenance throughout the life of the airframe. Fatigue is caused by repeated application of stress or force over a prolonged period. Critical joints or



Finite element analysis models of an aircraft such as the one shown here are created to help identify fatigue-critical locations.

SwRI-designed-and-built recorders are mounted in aircraft to gather structural load data.

SSGT Jeffrey Allen, USAF



Holes are drilled in a material test sample to replicate fatigue-critical locations. The sample is then instrumented and subjected to various loads to study crack growth.

fasteners make up the majority of these FCLs and are continually tracked by ASIP engineers. As an aircraft ages and its usage changes, these FCLs change, with additions made as field maintenance and ground testing uncover new areas of concern or as an aircraft structure is upgraded.

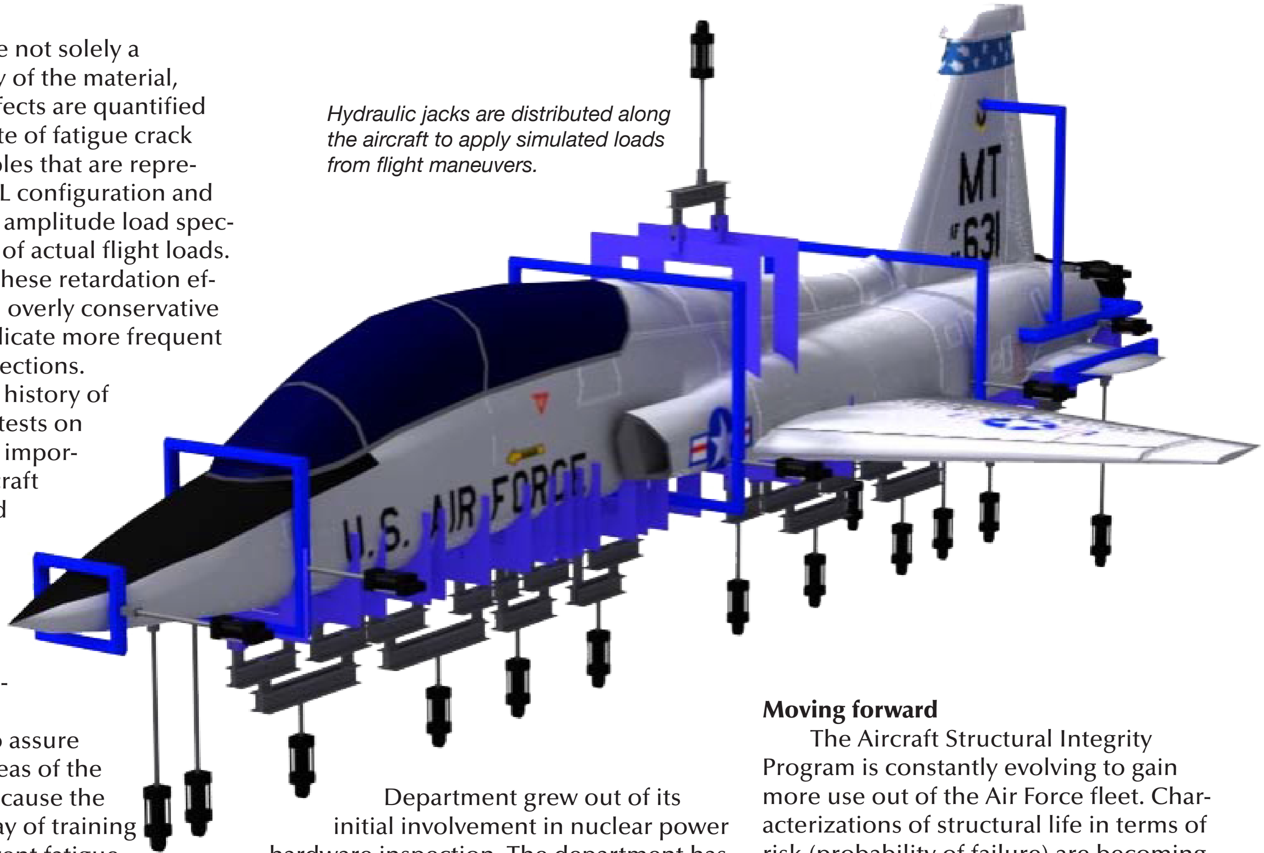
When locations throughout the aircraft structure are identified as FCLs, the appropriate analyses are identified to understand the potential for fatigue or failure. These locations often are associated with fastener holes used to build the structural assemblies for wings, stabilizers, fins and engine mounts, among other items. Analytical modeling provides the predicted fatigue life of the FCLs. A large finite element analysis (FEA) model is created to provide the overall loads and deflection responses for the entire aircraft when the appropriate load distributions are applied. More detailed responses are often needed in the vicinity of the FCLs in the FEA model. Thus, the large model is augmented with very finely detailed FEA models that capture the details of geometry and attachments that are key to predicting how flaws in these areas grow into critical fatigue concerns such as cracks. The growth and migration of these flaws are then addressed by a battery of fatigue crack growth analysis packages, each geared to the type of flaw progression expected in an FCL. If possible, these analyses are confirmed using an array of material laboratory testing and larger ground testing.

Materials studies, structural testing and nondestructive evaluation

Various aerospace materials — aluminum, steel, titanium and more recently, composites — are developed to provide strength and crack growth resistance for each FCL. Characterizing the mechanical behavior of these materials as well as quantifying the means in which a fatigue crack propagates, or grows, is performed by SwRI's Materials Engineering Department. With an understanding of damage tolerance assessment (DTA) methodology, unique testing is designed and executed to determine the fatigue and fracture properties characteristic of each material. DTA assesses how long damage can be sustained before a repair is made. Additionally, for many aerospace materials, the fatigue crack growth behavior is also dependent on the load history. The periodic occurrences of more severe loadings, such as those resulting from turbulence, aggressive or evasive maneuvers or heavy landings, can actually have a beneficial effect by temporarily slowing, or retarding, the rate of fatigue crack growth. Though it may appear counterintuitive, these severe loads can create temporary local zones near the flaw sites that inhibit fatigue cracks from passing through them. While not solely a mechanical property of the material, these retardation effects are quantified by measuring the rate of fatigue crack growth on test samples that are representative of each FCL configuration and subject to a variable amplitude load spectrum representative of actual flight loads. Not accounting for these retardation effects would result in overly conservative assessments and indicate more frequent or unnecessary inspections.

SwRI has a long history of performing ground tests on aircraft to ensure all important areas of the aircraft structure are tracked properly. Currently SwRI has two sets of T-38 aircraft wings mounted on fuselage sections to conduct full-scale fatigue tests of flight hardware to assure that all important areas of the wing are tracked. Because the T-38 provides an array of training functions, two different fatigue tests are needed to properly reflect the two very different missions flown by the aircraft. The T-38 is used as the first high-performance trainer that new Air Force pilots use to “get their wings.” Thus, one of the wing tests reflects this kind of less severe usage. Since it is a high-performance supersonic trainer, Air Force pilots selected to become fighter pilots use the T-38 in another training sequence to begin their aggressive combat maneuver training. This much more demanding flying is reflected in the loads used for the other wing fatigue tests. Testing ranges from investigating key structural upgrades in the aircraft’s primary structure to suspending an entire aircraft in an SwRI-designed frame that uses hydraulic jacks to simulate in-flight distributed loads.

Measuring the aircraft’s hardware state-of-health is essential to assess airframe life. This entails testing and regular inspections. SwRI’s Sensor Systems and Nondestructive Evaluation Technology Department grew out of its initial involvement in nuclear power hardware inspection. The department has an Air Force-recognized superior capability to design sensing hardware, devise supporting hardware, develop calibration standards and inspection methods, and perform the most demanding inspections for aircraft structures. SwRI has designed sensors and calibration mechanisms that have been pivotal for nondestructive testing of the T-38 and A-10. SwRI engineers are also developing sensors that can be implanted in an airframe to provide structural health monitoring to improve prevention strategies.



Hydraulic jacks are distributed along the aircraft to apply simulated loads from flight maneuvers.

Moving forward

The Aircraft Structural Integrity Program is constantly evolving to gain more use out of the Air Force fleet. Characterizations of structural life in terms of risk (probability of failure) are becoming more useful to support decisions about repair or replacement of an airframe structure. SwRI ASIP engineers are at the forefront in developing and employing these tools for the Air Force. SwRI has invested in development efforts that focus on better nondestructive evaluation and improved flaw growth analysis methods. Moving forward, a new family of aircraft structures is being introduced that uses advanced filamentary composite structural materials. These new materials are significantly affecting ASIP processes. SwRI researchers are among the cadre of Air Force and industry aircraft structural engineers conducting research into how these materials change the nature of ASIP, and are developing analyses, processes, and evaluation methods to ensure safe operation of advanced aircraft.

SwRI-designed, field-portable sensors allow on-site inspection of aircraft, such as the F-16 shown here.

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This Hybrid Can Really Fly

SwRI engineers have developed a small gas turbine generator to power hybrid unmanned aircraft systems

By John Bishop and David Ransom, P.E.

An existing SwRI-developed gas turbine design was adapted to power a generator for use in small unmanned aerial vehicles.

Small, autonomous unmanned aerial systems (UAS) have grown increasingly popular for varied applications, both military and civilian. Besides surveillance and weapons delivery systems, they are useful in crowd management, air sampling, aerial imagery, and environmental and wildlife surveys. Typical unmanned vehicles tend to be smaller, quieter and less conspicuous than manned aircraft, and they can be operated in environments that are too toxic or dangerous for human operators. However, their relatively small fuel volume limits both their range and performance. Electric-powered vehicles, which excel where quiet operation is desired, are limited even more by battery weight and frequent recharging.

The search for a quiet UAS with adequate speed and range requires a reconsideration of traditional power plants. In response to a government client's request to develop such a system on a relatively short schedule, an interdivisional team of engineers was formed at Southwest Research Institute (SwRI). The team developed a novel, hybrid power system that combines the speed and range of turbine power with the lower noise level of electric power. The lightweight gas turbine generator, when combined with an electric propulsion system, allows the aircraft to reach distant targets quickly and efficiently.

The SwRI team custom-designed, built and tested a novel gas turbine to drive an electric generator. The hybrid electric configuration allows the UAS to operate using either the gas turbine or the battery and electrical system for propulsion. Including a gas turbine greatly extends the operating range compared to a traditional electrically powered UAS.

Hybrid UAS design challenges

The SwRI team designed a fuel-to-electricity generator using a single-shaft gas-turbine generator system that originated with an earlier, non-flying patented SwRI gas-turbine configuration. Repurposing the original SwRI gas turbine generator design required five major iterations and many hours addressing design elements such as layout, rotor dynamics, aerodynamics, mechanical components, combustor design, lubrication and fuel systems and noise control.

The final fuel-to-electricity generator integrated a commercially procured generator/motor with the SwRI-designed-and-built gas turbine system. Throughout the extensive design process, engineers evaluated each design iteration for factors such as weight, performance and manufacturability. Although the gas turbine system is relatively conventional, the fifth and final design concept incorporated a number of unique features.

Because of the high rotation speed of the SwRI gas turbine, the rotordynamic design was a critical element. SwRI's plan was to develop a simple, single-rotor system with minimal separate lubrication system requirements. In addition, the design team wanted a simple, integrated motor-generator system. The gas turbine generator was modeled and analyzed, with numerous changes to the shaft configuration, bearing sizes, location and

John Bishop (left) is a program manager in the Applied Physics Division. His primary focus includes projects that develop various types of vehicles and other mechanical support equipment. He also develops test systems and procedures and analyzes test results. His prior experience includes design and testing of gas turbine engine compressor components.

David Ransom (right) is manager of the Machinery Structural Dynamics Section within SwRI's Mechanical Engineering Division. His research interests include dynamic system modeling and analysis, experimental programs and root cause failure analysis. His work is divided between the energy industry, including hydrocarbon-based and renewable technologies, and the aerospace industry, primarily focused on liquid and air-breathing propulsion.

shaft damping. In the final configuration, the bearings are located on either side of the rotor with an overhung compressor and turbine system. The analyses indicated that a softly supported bearing structure on the motor inlet was necessary to improve shaft dynamic response.

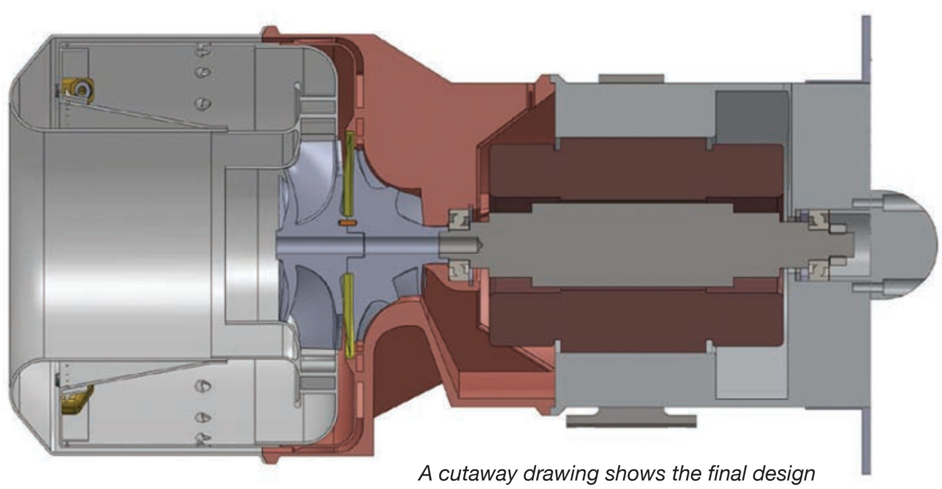
Components of the turbine system were designed using commercial off-the-shelf software intended for detailed aerodynamic, mechanical design and analysis of gas turbine components. During the preliminary aerodynamic design process, the SwRI team estimated mechanical stress to ensure the proposed aerodynamic design would operate at reasonable stress levels. Once the final (or nearly final) aerodynamic configurations were set, all rotating components were subjected to detailed stress analysis. The overall design process was structured to eliminate as many iterations as possible. SwRI engineers developed the aerodynamic designs of the compressor (rotor and diffuser) and the turbine (rotor and nozzles) using 1D and 3D aerodynamic design tools. Similar tools were used to analyze and design the remaining portions of the primary flow path, from the inlet of the engine through to the exhaust.

The SwRI team did an extensive investigation of existing combustor configurations and also studied fuel mixing times, evaporation rates and the combustion process. The combustor was modeled and analyzed using computational fluid dynamics (CFD) modeling. The design team eventually settled on a conventional annular combustor with a liner. Because the combustor is very small, the orientation of the fuel nozzles was adjusted to maximize the spray area volume while minimizing the number of nozzles. The extensive analyses yielded a high degree of confidence that the combustion would light off and burn effectively and efficiently and not fail unexpectedly.

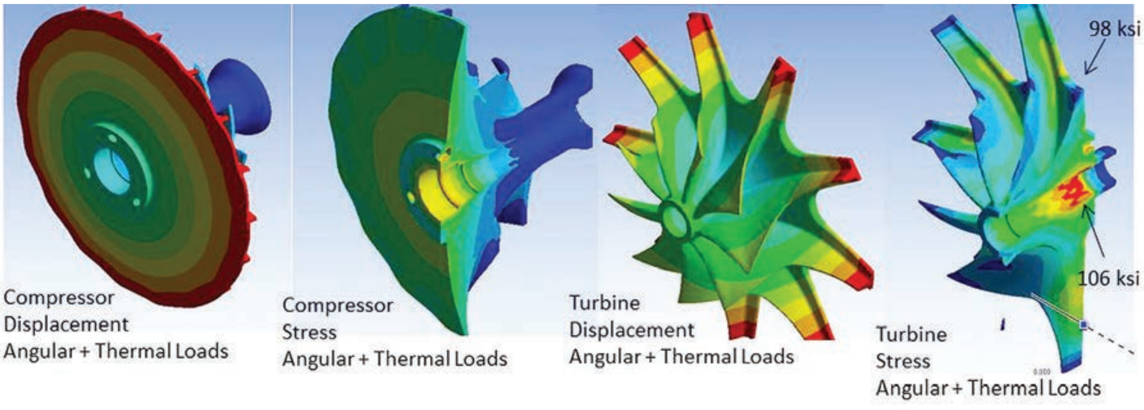
Component mechanical analysis

The component design process included a broad range of analyses to investigate the effects of mechanical stresses from angular velocity, thermal stress, interference fit for stress and assembly/stack tolerance, tie bolt stress, and fit and modal vibration.

Once the static and rotating components were designed, the SwRI team performed a final modal frequency analysis of rotating components to verify any potential for blade excitation from static components. The interaction between static structural components and rotating components could result in vibrations of the wheels, the turbine disk or the blade surfaces. Because the wheel is fairly rigid, the main area of concern was excitation of either the compressor or turbine blades. Without this critical step, the final design could easily suffer a component failure.



A cutaway drawing shows the final design configuration for a gas turbine generator.



Computation modeling analyzed stress and deflection for angular velocity and thermal loads for turbine disk designs.

The turbine disk is visible in the prototype's interior, with the plastic inlet duct in the right foreground.

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Selecting and integrating the motor-generator

Given the focus of the project on the design and build of the gas turbine system, the team sought out a commercially available motor-generator system that would not require excessive development. Although the aerodynamic portion of the gas turbine system can incorporate very high shaft speeds (around 250,000 rpm), the most viable motor-generator available for use in this project had a maximum safe operating speed of 118,000 rpm; therefore, this became the design operating speed for the new gas turbine.

To minimize weight, package size and complexity, the SwRI team integrated the motor-generator into the SwRI-designed gas turbine. To meet the program's compressed schedule, the motor-generator's final rotor design configuration was done in parallel with the gas turbine design, using an unfinished motor-generator rotor from the supplier. In the end, the parallel development project resulted in a well-integrated motor-generator and gas turbine system.

Unique features

An interesting feature of the power plant is the two-bearing support system on either side of the motor-generator, and an overhung compressor and turbine. The hybrid system uses ceramic bearings located on either end of the motor-generator's rotor with a minimal lubrication scheme. Typical oil lubrication systems require the circulation of a significant amount of lubricant through the bearings and then back to a sump for cleaning, cooling and pumping. They require more shaft space to meet the sealing requirements and additional hardware associated with cooling, cleaning, storing and pumping the lubricant. A minimal lubrication system, on the other hand, slowly drips oil into the bearing system, reducing the oil flow rate by two orders of magnitude. It is an open-cycle system in which the lubricant becomes a consumable during the gas turbine cycle. The low oil flow requirement allows a very simple lubrication scheme where the oil and cooling air are pulled through the bearings and into the gas turbine with no adverse effects. This bearing system is simple and minimizes the losses that would exist in a machine with multiple shafts, additional bearings and a typical jetted lubrication system.

Another feature simplifies cooling the generator during operation by using compressor inlet air. The resultant heating of compressor inlet air by 5 degrees F creates a small performance penalty, but the SwRI team considered this penalty as preferable to a cooling system that would require a separate fan or a liquid-cooling system with the associated cost, performance loss and weight penalty.

Component fabrication process

The SwRI-designed machine was fabricated using a number of unusual features. The hot section (the stator and combustor portion) was produced using a direct metal laser sintering (DMLS) process that enabled the team to build an intricate part that would typically be developed through the formation and assembly of several formed sheet metal parts. Because this was a prototype, not intended for production, investment in the forming process would have been cost-prohibitive. The DMLS process was critical in enabling the proper combustor design while still being representative of a potential final flight configuration.

The engine inlet duct was made of plastic material using a 3-D printer. Because the duct encounters only relatively cool inlet air, the material strength requirements are low. Meanwhile, 3-D printing enabled the team to easily manufacture the part's contours and hole pattern without excessive machining or molding costs. The holes in the inlet duct reduce gas turbine inlet noise, and the cavity behind the holes can be filled with sound-absorption materials.

The compressor and turbine are radial configurations made of titanium and Inconel alloy 718, respectively. The SwRI team originally planned to manufacture the turbomachinery wheels using DMLS. However, the only vendor capable of achieving the material strength requirements using DMLS was unavailable for hire. Therefore, the team was required to modify the design such that it could be manufactured using conventional five-axis machining.

Testing the system

The team developed a general test plan and several sub-plans to test subsystems or specific features of the system. The general plan allowed for a cumulative build of the system, checking each sub-system prior to adding the next sub-system. The test plan consists of a multi-phase process designed to evaluate subsystems individually before testing the entire power assembly.

SwRI developed a LabView™-based data acquisition system for monitoring the instrumentation controlling its various systems, including the motor-generator, fuel pump and igniter. In all, four emergency buttons were installed to allow operators to safely shut down the system from numerous locations within the test cell.

Some facility improvements were incorporated at SwRI's facilities for safe and effective testing, including a containment vessel surrounding the machine to protect from a potential rotor burst event.

Conclusion

The SwRI-developed gas turbine generator was successfully built and partially commissioned during this project. The SwRI team performed some initial machine runs and demonstrated a number of major system milestones.

The combustor was able to ignite at 25 percent of rated machine speed, validating the combustor and air-assist fuel nozzle designs. The mechanical integrity of the turbine and compressor wheels was demonstrated, validating the mechanical design.

The minimal bearing lubrication system worked well, and bearing temperatures and noise were low. The overhung turbine and compressor demonstrated good rotor dynamics, and critical shaft speeds were close to predictions. The softly supported rotor system allowed tuning to meet the machine requirements. *In-situ* rotor system balancing resulted in very low vibration levels, and the compressor met aerodynamic performance predictions.

The final machine was delivered to the client after testing at SwRI. The completed power system is expected to undergo continued development and testing to prove and possibly expand its capability. With further development the machine could be ideally suited for operation in a hybrid UAV system. In addition, it could be used to develop other new applications for the patented SwRI-developed gas turbine as a power source.

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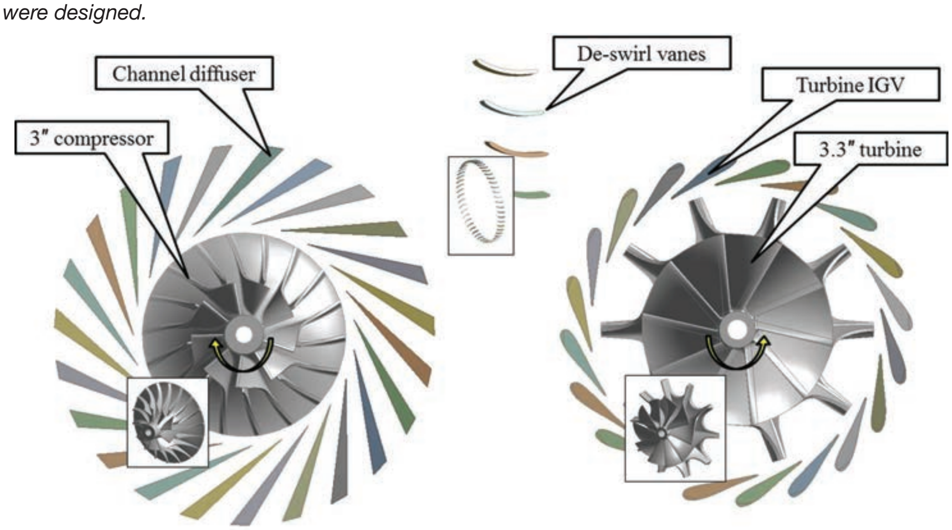
Sensors were fitted to the prototype during testing.

Questions about this article? Contact Bishop at (210) 522-5025 or john.bishop@swri.org.; or Ransom at (210) 522-5281 or david.ransom@swri.org.

This drawing shows how the gas turbine's aerodynamic components were designed.



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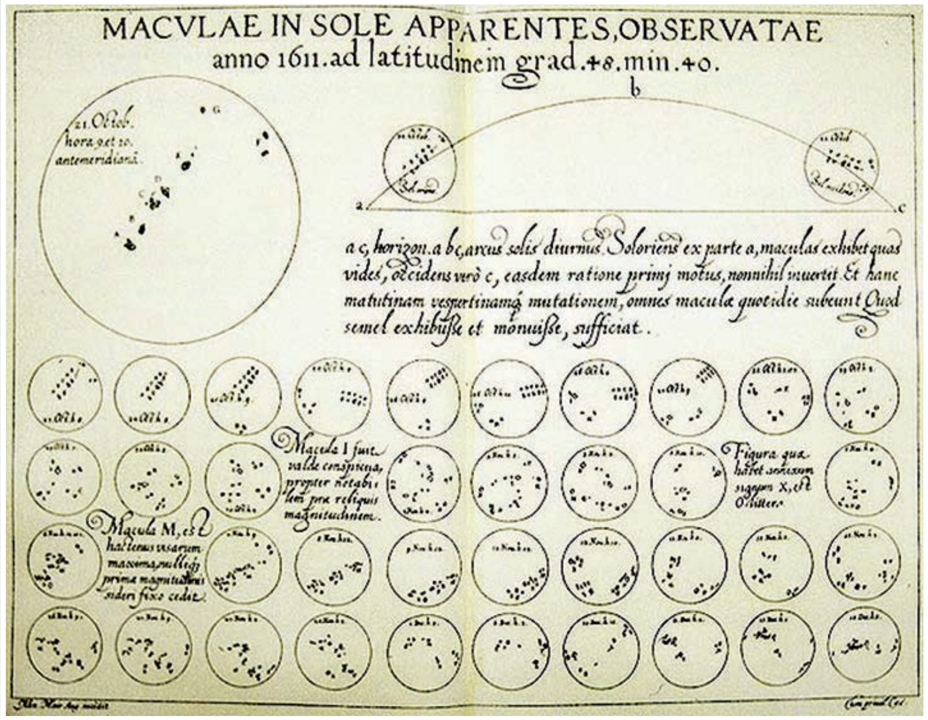
The Quiet Sun

SwRI scientists have discovered the weakest solar wind of the Space Age

By David J. McComas, Ph.D.



This sunspot map was created by German astronomer Christoph Scheiner around 1611.

Although space scientists have only been able to directly measure the Sun's solar wind since the Space Age began a little over 50 years ago, astronomers more than four centuries ago were already viewing the Sun and recording the appearance of dark areas, or "sunspots," on the solar surface. Over time they recognized that sunspot activity seemed to increase and decrease according to a cycle from "solar minimum" to "solar maximum" and back to minimum again, approximately every 11 years. Their increasingly accurate record of sunspots over the solar cycles remains useful to solar and space scientists today.

As knowledge of the Sun has continued to build, scientists have learned that the Sun constantly emits a continuous million mile-per-hour stream of charged particles, known as the solar wind. This solar wind inflates a "bubble" in space known as the heliosphere encompassing the solar system's planets. The solar wind was first directly measured by a Soviet spacecraft in 1959, with essentially continuous observations available largely from NASA spacecraft since the 1960s.

Meanwhile, sunspots are recognized today as regions of intense magnetic activity on the Sun. Some of these regions are associated with coronal mass ejections, or CMEs. CMEs are huge eruptions of electromagnetic energy from the corona, the superheated region area above the Sun's surface that is observable during eclipses. CMEs hurl some of the matter that makes up the Sun toward Earth and the other planets, often even faster than the already supersonic solar wind. Thus, space-age observations using *in-situ* solar wind measurements from space along with remote observations of the Sun have helped space physicists gain a much clearer understanding of the link between sunspots and those coronal mass ejections that collide with Earth's own magnetic field and create intense space weather events and stunning *aurora borealis*.

This *in-situ* knowledge helps today's scientists better understand the centuries-old observations of solar cycles. Over the most recent decade, scientists at Southwest Research Institute (SwRI), in collaboration with colleagues from a variety of other institutions, have noted an unexpected development. Associated with the unusually long most recent solar minimum and surprisingly low solar activity in the ongoing "mini" solar maximum, they observed the weakest solar wind of the space age.

The recent deep solar minimum and "mini" maximum

The last solar minimum, which extended into 2009, was especially deep and prolonged compared to previous solar cycles. Since then, sunspot activity — which would have been expected to rise toward a new peak— has instead gone through a very small peak of only about one-third the number of most recent cycles, even as other cyclical heliospheric behaviors, such as the tilt of the heliospheric electrical current sheet (which is greatest at the peak of the solar cycle and flattest at its minimum) were similar to what was seen in prior solar maxima. Compared to values typically observed from the mid-1970s through the mid-1990s, the solar wind output was, on average, dropping through the extended solar minimum and remained more than one-third lower in many key parameters

Solar Dynamics Observatory/NASA

Dr. David McComas is assistant vice president of SwRI's Space Science and Engineering Division. He is principal investigator for NASA's Interstellar Boundary Explorer (IBEX) and Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS) missions, and for the solar wind instruments onboard the Ulysses and the Advanced Composition Explorer (ACE) spacecraft. Those instruments produced much of the data in this article. He is author of more than 500 refereed publications and recipient of the 2014 COSPAR Space Science Award, recognizing outstanding contributions to space science.

during the mini solar maximum from 2009 and into 2013.

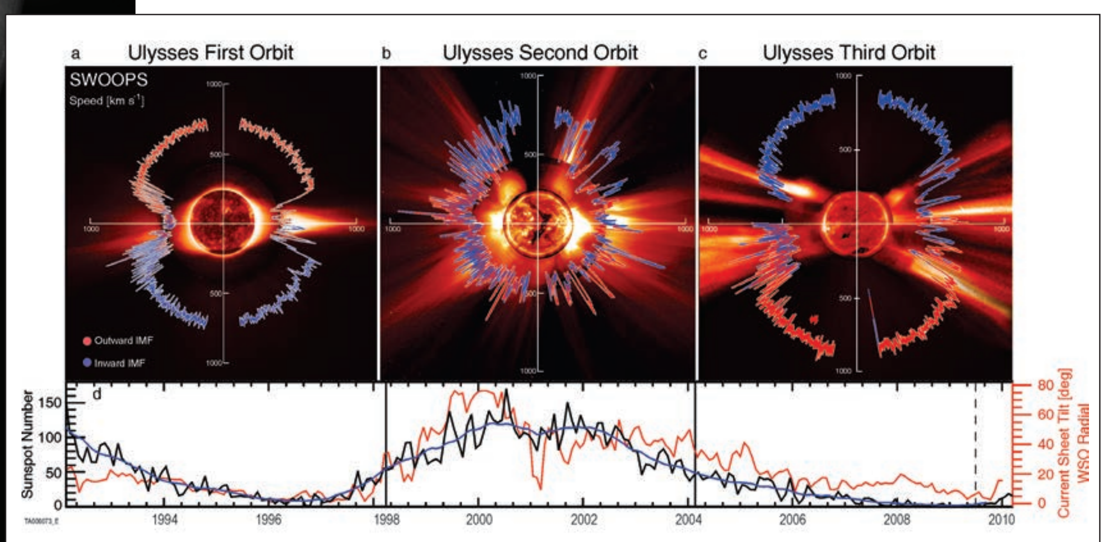
A weaker solar wind

Routine solar wind observations since the 1960s have led to essentially continuous measurements of the solar wind and its embedded interplanetary magnetic field. The SwRI team's study of data gathered by NASA's Ulysses spacecraft, launched in 1990 for an intended single six-year polar orbit around the Sun but whose mission eventually provided information from three solar orbits over nearly two decades, showed that the fast solar wind in the third orbit was slightly slower and cooler than the first orbit and had significantly lower density, mass flux and momentum flux. Other studies from Ulysses also showed that the magnetic field that extends out from the Sun's polar coronal "holes" and is associated with the fast wind was about one-third weaker in the third orbit compared to its first orbit.

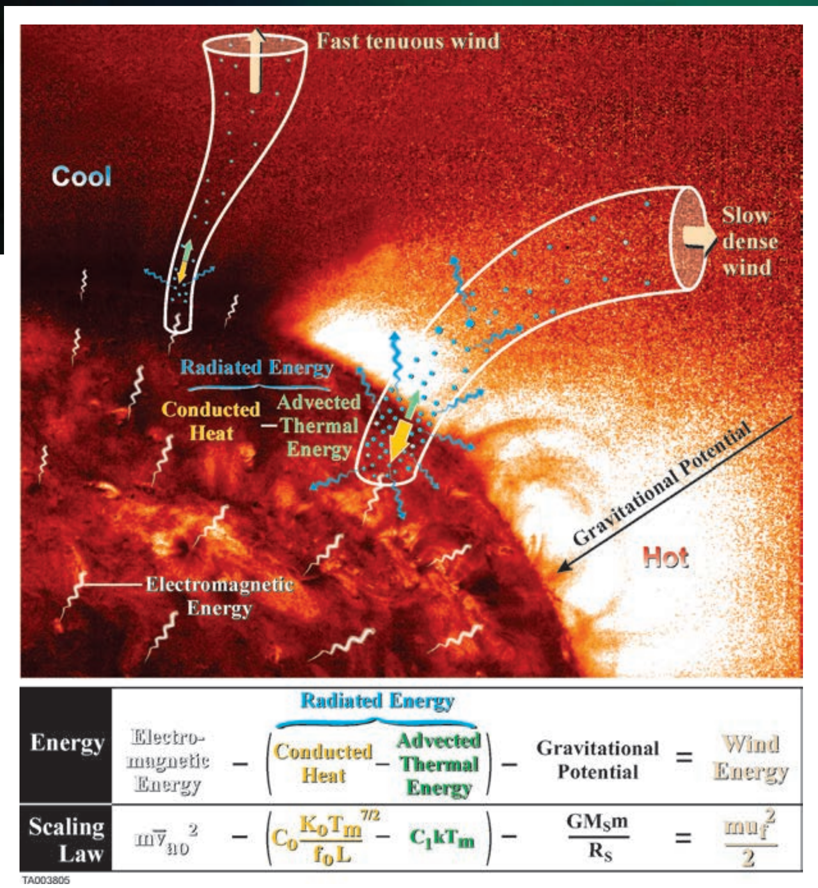
Overall, the studies showed that the recent extended solar minimum consistently produced the lowest solar wind output from the Sun since continuous and well-intercalibrated observations began in 1974, and likely over the entire Space Age. This output marked some of the lowest non-transient solar wind densities, proton temperatures, dynamic pressures and interplanetary magnetic field strengths ever observed.

The question of what causes the reduction of solar wind output through the last solar minimum and into the current solar maximum requires insights into the evolution of the coronal environment. Based on charge-state data from the Ulysses and ACE (Advanced Composition Explorer) spacecraft, the corresponding reduction in solar wind particle flux and solar wind power is likely associated with lower electron temperatures down in the corona.

One model useful in understanding solar behavior is the "solar wind scaling law" developed by two SwRI space scientists in 2003. The law shows that cooler coronal electron temperatures are naturally associated with lower solar wind particle fluxes during the protracted solar minimum, because downward heat conduction must be reduced to keep the average energy loss per particle fixed. Results of the scaling law suggested that the evolution of the solar wind is linked to the Sun's internal dynamo, which produced a weaker coronal magnetic



The Ulysses spacecraft measured solar wind speed (red and blue lines in radial plots) overlaid on typical coronal images for the different epochs and comparing to the sunspot numbers and current sheet tilt across the bottom of the panel.



The solar wind scaling law (equations shown at bottom of graphic) links cooler coronal electron temperatures with lower solar wind particle fluxes during a solar minimum. Results of the law suggest that the evolution of the solar wind is linked to the Sun's internal dynamo, which produced a weaker coronal magnetic field during the recent deep, extended solar minimum.

field during the deep, extended solar minimum. The law was used to project coronal electron temperatures backward in time throughout the space age and found that while these coronal temperatures had been increasing in successive temperature maxima from 1969 to 1987, since then they have been decreasing in successive maxima.

The central question remains as to why the dynamic pressure remains so low through the recent solar maximum. At least part of the answer is that the coronal environment remains in a state similar to that in the previous solar minimum. In fact, the studies show that while interplanetary magnetic field strengths have risen, they have only risen to levels that are still quite a bit lower than they were in the previous cycle. Ultimately, the mechanistic relationship between the Sun's magnetic field and solar wind outflow implicates the Sun's internal dynamo as the underlying energy source, and hence regulator of the solar wind. The relationship between low sunspot numbers and low solar wind power demonstrates the widespread effects of the reduction of the Sun's open magnetic field in the mini solar maximum.

A separate study by Owens and Lockwood in 2012 examined the imbalance between open solar flux sources and losses, including geomagnetic observation inferred values back to 1868 and sunspot inferred values back to 1610. The study connected the last two solar minima with features of the Maunder Minimum, a period of unusually low sunspot activity between 1645-1715 named after its discoverer, British astronomer Edward Walter Maunder, and suggest that the recently observed large current sheet tilt despite low CME rates and sunspot numbers also may have been present in the Maunder Minimum. (A similar period, named the Dalton Minimum after English meteorologist John Dalton, lasted from about 1790 to 1830).

It remains to be seen if the most recent solar wind observations are heralding a new long-term Dalton or Maunder-like minimum. In any case, these are exceptional times, with the Sun producing its weakest output of the Space Age through both the protracted solar minimum and current mini solar cycle maximum.

What happens next?

A key question for the current maximum is how the Sun recovers from the protracted, low-activity solar minimum that preceded it. The team re-analyzed data from that period to glean any information about increasing coronal temperatures

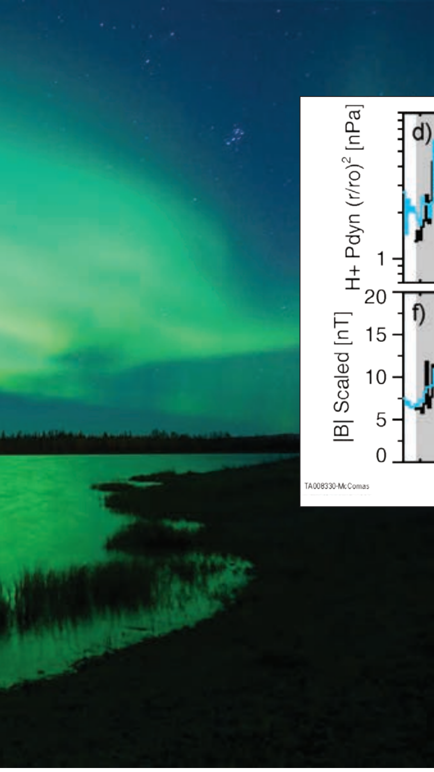
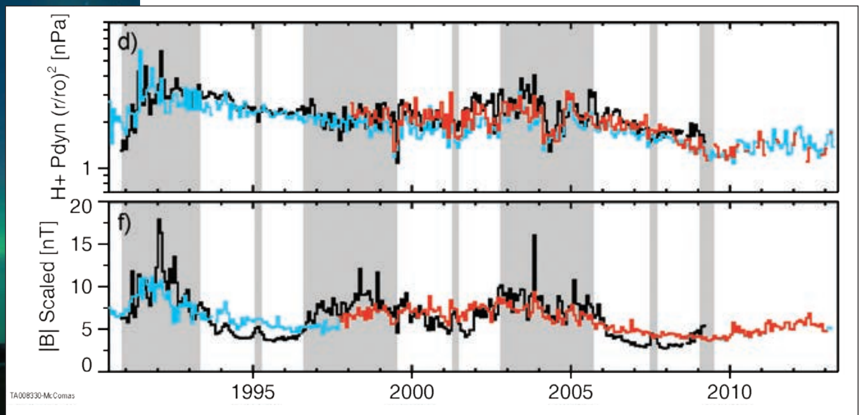


Image courtesy of Bud Kuenzli, NASA



Solar wind dynamic pressure (top) and interplanetary magnetic field magnitude (bottom) over the past 25 years. Ulysses (black), ACE (red) and other spacecraft (blue) all show that both the pressure and field are significantly lower than a decade ago, and have remained lower even through the current mini solar maximum.

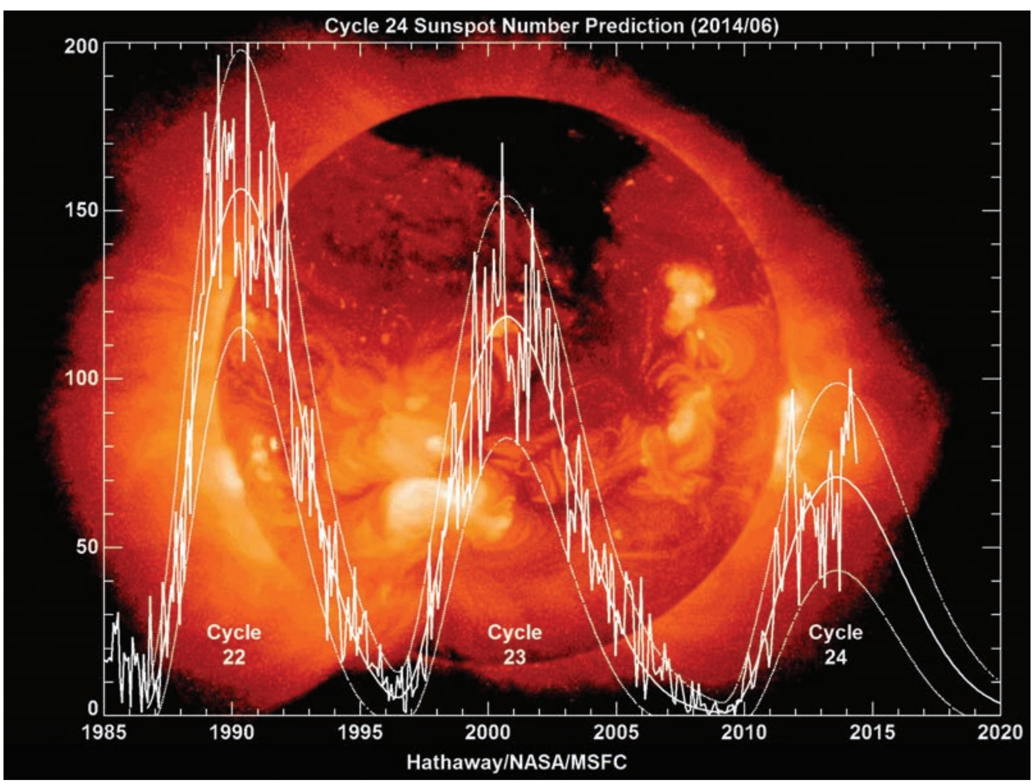
from charge states as temperatures rose toward a new maximum. The key observational result is that coronal temperatures did increase toward the recent cycle maximum, but they did not recover to anything close to their highs of the previous cycles. In addition, the new study also showed that after that increase, there was a drop of coronal temperatures in the most recent data. This suggested that we may have already passed through the current solar maximum in 2013. Coronal temperatures continue to show remarkably low values indicative of the anomalous lack of solar activity in the era that began approximately in 2005. Since then sunspots have gone through a second small peak, similar in magnitude to that in 2013 and far lower than in recent previous cycles.

In other recent work, insights into the evolution of the interplanetary magnetic flux were used to determine its time history based on sunspot numbers going back to 1749. Sunspot records from the Dalton Minimum resemble those of the past 15 years, and at this point the sunspot number is comparable to what was seen during the first reduced maximum of the Dalton Minimum era. The years following 1805 therefore may serve as a predictor for the coming 10 years of solar activity. With the 10-year predictions of sunspot number, the same theory was applied to determine the levels of interplanetary magnetic flux. The conversion of magnetic flux to particle flux, and application of the solar wind scaling law to infer coronal temperature, indicates that temperatures could fall to levels even lower than were observed in the previous two solar minima.

Questions about this article? Contact McComas at (210) 522-5983 or david.mccomas@swri.org.

Acknowledgment

The author thanks NASA for sponsoring this work and the members of the Ulysses and ACE mission teams. The author gratefully acknowledges contributions to the research involved in this article by Dr. Heather Elliott and Dr. George Livadiotis of the SwRI Space Science and Engineering Division and Dr. Nathan Schwadron, previously of SwRI and now at the University of New Hampshire.



Sunspot numbers at the peaks of the last three solar cycles show a declining pattern, with a significantly weaker twin-peak maximum for the most recent cycle.

SwRI's Dedicated EGR® Technology Wins R&D 100 Award

An SwRI-modified sedan incorporates new technologies to improve performance while reducing emissions

A new engine design that improves fuel economy and lowers exhaust emissions has received a 2014 R&D 100 Award. *R&D Magazine* selected Southwest Research Institute's Dedicated EGR (D-EGR®) engine technology as one of the 100 most significant technological achievements introduced in the past year.

Dedicated EGR technology (see "Powering the Way to Better Fuel Economy," *Technology Today,* Summer 2013) is a novel engine architecture that is up to 15 percent more efficient than today's mainstream engines while simultaneously improving performance. It allows manufacturers to address future, more aggressive Corporate Average Fuel Economy (CAFE) standards and meet LEV III/Tier 3 emissions levels cost-effectively.

D019366_8285

To showcase the technology, SwRI engineers modified a current-production mid-size sedan's 4-cylinder 2.0 L gasoline engine so that exhaust from one cylinder, dedicated to EGR production, is run with a rich mixture of fuel and air to reform gasoline enriched into carbon monoxide and hydrogen. This "reformate" exhaust gas is then cooled and looped into a patented mixer where the EGR and reformate are mixed with fresh air before going into the engine intake.

"This technology developed by our automotive engineers is a significant leap forward in gasoline engine design. Recirculating exhaust gases this way improves engine efficiency and fuel economy while simultaneously lowering exhaust emissions," said Bruce Bykowski, vice president of SwRI's Engine, Emissions and Vehicle Research Division. "With our D-EGR demonstration vehicle, the Institute has a made a significant investment to validate the technology as a viable, production-ready alternative for automotive manufacturers."

The team of SwRI engineers designed several new components for the advanced combustion concept — the cooled EGR loop, the EGR mixer and high-energy ignition system — as well as engine-control software that enables in-cylinder fuel reformation.

Advances in engine design such as the D-EGR technology are especially critical given the current and upcoming regulatory climate. By 2025, automobile manufacturers will have to meet CAFE standards of 54.5 miles per gallon. The Environmental Protection Agency is also expected to release new, more stringent emissions standards. Those two factors mean there is considerable industry focus on simultaneously improving both emissions and fuel efficiency, challenges which SwRI's demonstration vehicle addresses.

"The D-EGR concept takes the best attributes of regular cooled EGR and combines them with in-cylinder reformer technology. We segregate the exhaust of a cylinder of the engine so that one cylinder provides all of the recirculated exhaust gas back into the intake manifold," said Dr. Terry Alger, assistant director in SwRI's Engine, Emissions and Vehicle Research Division.

"By running one cylinder rich, the excess fuel is reformed into hydrogen and carbon monoxide," added Chris Chadwell, manager of SwRI's Spark Ignition Engine R&D section. "The in-cylinder reformation slightly reduces the carbon dioxide and water vapor while producing large volumes of carbon monoxide, which is a good fuel, and hydrogen, which is an outstanding fuel. That provides an octane boost and a flammability boost."

SwRI has won 38 R&D 100 Awards since 1971. Widely recognized as the "Oscars of Invention," R&D 100 Awards are selected by an independent panel of judges and editors of R&D Magazine and identify and celebrate the top technology products of the year. This year's award will be presented November 7, 2014, in Las Vegas.

The Engine, Emissions and Vehicle Research Division, along with the Fuels and Lubricants Research Division, comprise SwRI's Automotive Engineering capabilities.

Questions about this article? Contact Alger at (210) 522-5505 or talger@swri.org.

TECHNICS

Brief notes about the world of science and technology at Southwest Research Institute

SwRI to lead separation technology joint industry project

Southwest Research Institute (SwRI) has announced a multi-million-dollar joint industry project to better understand oil and gas separation technology. The objective of the Separation Technology Research Program (STAR Program) is to combine industry knowledge and resources to advance research that could lead to better equipment and test protocols.

SwRI is leading the three-year program, which is open to operating companies, contractors and equipment manufacturers. International participation is welcomed and encouraged. The three-year membership ranges from $450,000 to $75,000 depending on the type of company.

"Separating fluid mixtures into streams of oil, natural gas and water efficiently and cost-effectively using lighter-weight equipment that requires less space is very important to the industry. The STAR Program will involve this three-phase separation process as well as gas/liquid separation and liquid/liquid separation," said Chris Buckingham, a program director in SwRI's Fluids and Machinery Engineering Department and manager of the STAR program.

Members of the program will guide research initiatives by developing a project scope, identifying technologies to be tested, providing input on standard test approaches, witnessing testing and commenting on results.

Goals of the program are to develop standardized testing methods, collect data to improve equipment performance and develop analytical models for various types of separation equipment.

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SwRI receives $1.8 million DOE contract award to demonstrate hydrogen compression

Southwest Research Institute (SwRI) will begin work on a $1.8 million contract award by the U.S. Department of Energy to develop, fabricate and test a linear motor reciprocating compressor (LMRC) to meet DOE's goals of increasing efficiency and reducing cost for hydrogen compression. The project paves the way toward economical hydrogen storage. At present, hydrogen storage is an expensive operation. Capital costs are high, and the equipment used is often inefficient and unreliable, leading to costly routine maintenance, repairs and downtime.

The LMRC is based on an SwRI-patented concept of driving a permanent magnet piston inside a hermetically sealed compressor cylinder through electromagnetic winding, thus minimizing mechanical part count, reducing leakage and ensuring better reliability.

SwRI's researchers expect the LMRC system will be able to achieve the required compression ratio with efficiency greater than 95 percent, greatly exceeding current equipment capabilities with efficiencies that are typically only about 73 percent.

"The SwRI design is more efficient than traditional compressors, and thus will require less energy," said Eugene Broerman, a senior research engineer in SwRI's Mechanical Engineering Division and manager of the DOE project. For more information about compression technology at SwRI, visit *www.machinery.swri.org*.

Contact Broerman at (210)-522-2555 or eugene.broerman@swri.org.

Laboratory models suggest that stretching forces shaped Jupiter Moon's surface

Processes that shaped the ridges and troughs on the surface of Jupiter's icy moon Ganymede are likely similar to tectonic processes seen on Earth, according to a team of researchers led by Southwest Research Institute (SwRI). To arrive at this conclusion, the team subjected physical models made of clay to stretching forces that simulate tectonic action. The results were published in *Geophysical Research Letters*.

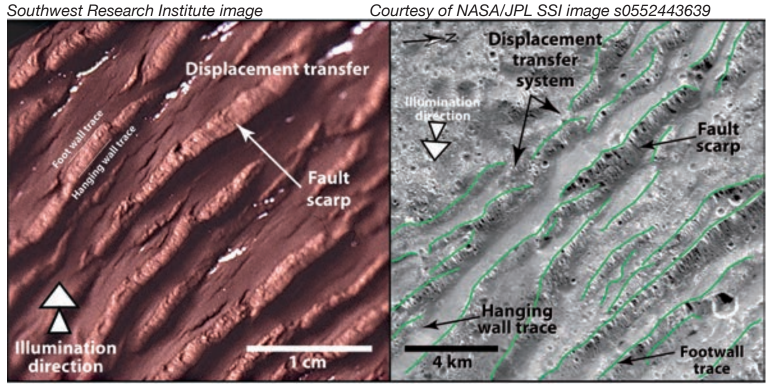
Physical analog models simulate geologic structures in laboratory settings so that the developmental sequence of various phenomena can be studied as they occur. The team – including researchers from SwRI, Wheaton College, NASA's Jet Propulsion Laboratory and NuStar Energy LP – created complex patterns of faults in their models, similar to the ridge and trough features seen in some regions of Ganymede. The models consisted of a "wet clay cake" material possessing brittle characteristics to simulate how the icy moon's lithosphere, the outermost solid shell, responds to stresses by cracking.

The laboratory models suggest that characteristic patterns of ridges and troughs, called grooved terrain on Ganymede, result from its surface being stretched. "The physical models showed a marked similarity to the surface features observed on Ganymede," said co-author Dr. Danielle Wyrick, a senior research scientist in the SwRI Space Science and Engineering Division.

The paper, "Physical Models of Grooved Terrain Tectonics on Ganymede," by D.W. Sims, D.Y. Wyrick, D.A. Ferrill, A.P. Morris, G.C. Collins, R.T. Pappalardo and S.L. Colton, was published by *Geophysical Research Letters,* 16 June 2014, Volume 41, Issue 11, pages 3774–3778 , (doi 10.1002/2014GL060359).

Contact Wyrick at (210) 522-6837 or danielle.wyrick@swri.org.

Southwest Research Institute image Courtesy of NASA/JPL SSI image s0552443639



An image of a tabletop-size analog model (left) shows details of fault systems created by extension that visually match an image by spacecraft Galileo of faulted terrain on Ganymede (right).

SwRI-led team's research shows giant asteroids battered early Earth

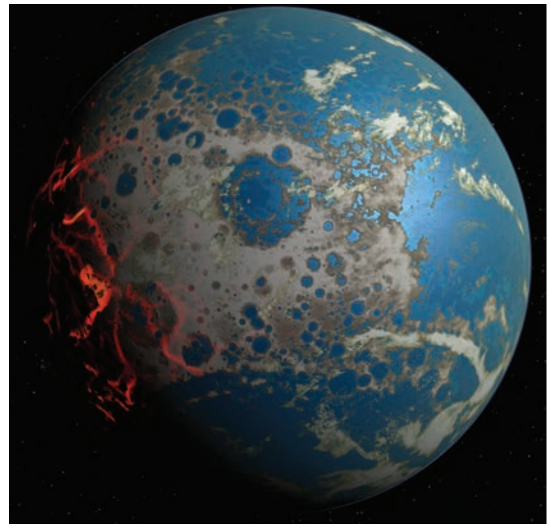


Image Courtesy of Simone Marchi

A new terrestrial bombardment model developed by an international group of scientists led by Southwest Research Institute (SwRI) indicates that Earth's surface was heavily reprocessed — or melted, mixed and buried — as a result of giant asteroid impacts more than four billion years ago.

The model, calibrated using existing lunar and terrestrial data, sheds light on the role asteroid collisions played in the geological evolution of the uppermost layers of Earth during the geologic eon call the Hadean, or first geologic eon.

The team, which also included academic and government researchers, published its findings in a paper, "Widespread Mixing and Burial of Earth's Hadean Crust by Asteroid Impacts," in the July 31, 2014, issue of the journal *Nature*.

"Prior to approximately four billion years ago, no large region of Earth's surface could have survived untouched by impacts and their effects," said Dr. Simone Marchi, lead author of the paper and a planetary scientist in SwRI's Planetary Science Directorate in Boulder, Colo. "The new picture of the Hadean Earth emerging from this work has important implications for its habitability," Marchi said.

Large impacts had particularly severe effects on existing ecosystems. Researchers found that on average, Hadean Earth could have been hit by one to four impactors that were more than 600 miles wide and capable of global sterilization, and by three to seven impactors more than 300 miles wide and capable of global ocean vaporization.

The team was comprised of Marchi and Dr. William Bottke from SwRI; L. Elkins-Tanton from the Carnegie Institution for Science in Washington; M. Bierhaus and K. Wünnemann from the Museum fur Naturkunde in Berlin, Germany; A. Morbidelli from Observatoire de la Côte d'Azur in Nice, France; and D. Kring from the Universities Space Research Association and the Lunar and Planetary Institute in Houston.

The research was supported in part by NASA's Solar System Exploration Research Virtual Institute (SSERVI) at NASA's Ames Research Center in Moffett Field, Calif. SSERVI is a virtual institute that, with international partnerships, brings science and exploration researchers together in a collaborative virtual setting. SSERVI is funded by the Science Mission Directorate and Human Exploration and Operations Mission Directorate at NASA Headquarters in Washington.

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NASA selects SwRI-led CubeSat mission studying solar particles and space weather

NASA has selected Southwest Research Institute (SwRI) to develop CuSPP, a CubeSat mission to study solar particles over the Earth's poles. SwRI will also lead mission science operations and data analysis.

CuSPP will fly as early as 2017. During the five-year project, engineers and scientists will design, develop and integrate a CubeSat — a nano-satellite launched as a secondary payload on another satellite mission — carrying a novel miniaturized Suprathermal Ion Sensor (SIS) developed at SwRI. The SIS will measure the sources and acceleration mechanisms of solar energetic particles that are harmful to astronauts as well as Earth-based technologies.

CuSPP can also support space weather research by measuring particles that escape ahead of powerful shock waves in the solar wind. Upon striking the Earth, solar particles and shock waves can cause severe electromagnetic storms, damage satellites, disrupt radio communication and navigation signals, damage electric power grids and corrode pipelines.

In addition, CuSPP is designed to measure the properties of ion populations entering the ionosphere, the uppermost portion of the Earth's atmosphere.

"Upon successful completion, we expect CuSPP to have achieved several key goals, such as increasing the technological readiness level and reducing the risks and costs of flying a new class of SwRI science instruments for studying heliophysics — the Sun's effects on the solar system," said Dr. Mihir Desai, CuSPP principal investigator and a staff scientist in the SwRI Space Science and Engineering Division.

A standard CubeSat is a 10-centimeter cube with a one-liter volume. CuSPP is 30 by 10 by 10 centimeters with a volume of three liters.

SwRI is collaborating with the NASA Goddard Space Flight Center, Greenbelt, Md., to produce the CubeSat, including the flight segment (integrated at SwRI), ground segment (provided by the NASA Wallops Flight Facility) and payload (developed at SwRI). CuSPP was selected as part of the 2013 Heliophysics-Technology and Instrument Development for Science (H-TIDeS) 2013 competition, with funding from the new NASA SMD-wide CubeSat initiative managed by NASA's Heliophysics Division.

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Technical Staff Activities

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Dayeh, M.A. "The Interstellar Boundary Explorer Mission: An Overview." Presented at the Department of Physics and Space Sciences, Florida Institute of Technology, Melbourne, Fla., April 2014.

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Desai, M.I. "Space Physics Research at SwRI and UTSA in San Antonio." Presented at the Witte Museum, San Antonio, May 2014.

Desai, M.I. "Space Weather and the UTSA/SwRI Graduate Program in Physics." Presented at the Jose Miguel Cimadevilla Memorial Seminar at St. Mary's University, San Antonio, February 2014.

Desai, M.I., D.J. McComas, E.R. Christian, A.C. Cummings, J. Giacalone, M.E. Hill, S.M. Krimigis, S.A. Livi, R.L. McNutt, R.A. Mewaldt, D.G. Mitchell, W.H. Matthaeus, E.C. Roelof, T.T. von Rosenvinge, N.A. Schwadron, E.C. Stone, M.M. Velli and M.E. Wiedenbeck. "Suprathermal and Solar Energetic Particles: Key Questions for Solar Probe Plus and Solar Orbiter." Presented at the Huntsville Workshop 2014: Solar and Stellar Processes from the Chromosphere to the Outer Corona, Orlando, Fla., March 2014.

Dickinson, J., C. Ruf, R. Rose, A. Ridley and B. Walls. "CYGNSS: The Cyclone Global Navigation Satellite System's CubeSat Foundations." Presented at the 11th Annual CubeSat Developers' Workshop, San Luis Obispo, Calif., April 2013.

Dickinson, J., J.L. Alvarez, L.T. McDaniel, J.R. Pruitt, B.J. Walls and K.P. Zajicek. "CYGNSS Command and Data Subsystem and Electrical Power Subsystem Phase A and B Developments." Presented at the 2014 IEEE Aerospace Conference, Big Sky, Mont., March 2014.

Dinwiddie, C.L., R.N. McGinnis, D.E. Stillman and K.L. Bjella. "Interpretation of Geophysical Interrogation of the Great Kobuk Sand Dunes, Arctic Alaska: A Terrestrial Analog Study." Presented at the 8th International Conference on Mars, Pasadena, Calif., July 2014.

Ebert, R.W., M.A. Dayeh, M.I. Desai, G. Li and G.M. Mason. "Constraining the Origin of CIR-associated Energetic Particles at 1 AU that Arrive from a Non-local Source." Presented at the AGU Fall Meeting, San Francisco, December 2013.

Egan, A. "Mars Reconnaissance Orbiter (MRO): SHARAD Observation Planning: A Geospatial Edge." Presented at the American Institute of Aeronautics and Astronautics (AIAA) SpaceOps 2014 13th International Conference on Space Operations, Pasadena, Calif., May 2014.

Evans, P. "Enabling Manufacturing Innovation in the U.S." Presented at the 2013 Center for Advanced Manufacturing and Lean Systems (CAMLS) Annual Meeting and Industry Advisory Council (IAC) Event, San Antonio, November 2013.

Evans, P.T. "Cloud-based Manufacturing." Panel at the 24th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM), San Antonio, May 2014.

Finley, T., D. Rose, K. Nave, W. Wells, J. Redfern and C. Ruf. "Techniques for Low Earth Orbit (LEO) Constellation Deployment and Phasing Utilizing Differential Aerodynamic Drag." Presented at the AAS/AIAA Astrodynamics Specialist Conference, Hilton Head Island, S.C., August 2013.

Flannigan, W.C. "Panel for Manufacturing Standards – Robot Operating System Industrial (ROS-I)." Presented at the American Society of Mechanical Engineers (ASME) Advanced Manufacturing Impact Forum, San Diego, November 2013.

Flannigan, W.C. "ROS-Industrial Consortium Americas Status Update." Presented at the Fraunhofer R&D Management Conference 2014, Stuttgart, Germany, June 2014.

Flannigan, W.C., S. Edward and P. Hvass. "ROS-I Session." Presented at the RoboBusiness Leadership Summit, Santa Clara, Calif., October 2013.

Fritz, S. and M. Shurland. "Locomotive Exhaust Emissions Measurements for Various Blends of Biodiesel Fuels." Presented at the 2014 Joint Rail Conference, Colorado Springs, Colo., April 2014.

Goldstein, J., C. Kletzing, W. Kurth, S. De Pascuale and K. Genestreti. "Plasmapause Test Particle Simulations for the Van Allen Probes Mission: Comparison with the Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS) and Updated Code." Presented at the Radiation Belt Storm Probes (RBSP) Science Working Group Meeting, Laurel, Md., March 2014.

Goldstein, J.H., J.H. Waite, J.L. Burch and T.W. Hill. "Model of Rotating 2-Cell Convection at Saturn, and Other Plasmasphere Modeling, at Earth." Seminar at Rice University, Houston, April 2014.

Grava, C., J.-Y. Chaufray, K.D. Retherford, G.R. Gladstone, T.K. Greathouse, D.M. Hurley, R.R. Hodges, A.J. Bayless, J.C. Cook and A.S. Stern. "Simulation of Lunar Exospheric Argon: Insights on Loss Processes, Cold-Trapping, and Sudden Release Events." Presented at the 44th LPSC Conference, The Woodlands, Texas, March 2014.

Gutierrez, G.E. "Novel Treatments for Osteoporosis." Presented at the National Congress of Mexican Orthopedic Surgeons, Mexico City, May 2014.

Gutierrez, G.E. and G. Rossini. "Development of Novel Statin Formulations to Treat Reperfusion Injury." Presented at the Military Health Research Symposium, Fort Lauderdale, Fla., August 2014.

Hanley, J., M. Mellon and R. Ardvison. "Mechanical Strength of Martian Analog Soils." Presented at the 8th International Conference on Mars, Pasadena, Calif., July 2014.

Hansen, G. and P. Lee. "Developing a Screener Test for the Cummins ISB Camshaft and Tappet Interface." Presented at the 2014 Society of Tribologists and Lubrication Engineers (STLE) 69th Annual Meeting, Lake Buena Vista, Fla., May 2014.

Hansen, J., G. Willden, B. Abbott and R. Green. "Ultrasonic Culvert Inspection System: Low-cost Device for Conduit Inspection." Presented at the Transportation Research Board (TRB) 93rd Annual Meeting, Washington, D.C., January 2014.

Hayne, P.O., K.D. Retherford, E. Sefton-Nash and D.A. Paige. "Temperature and Ultraviolet Albedo Correlations in the Lunar Polar Regions: Implications for Water Frost." Presented at the 44th LPSC Conference, The Woodlands, Texas, March 2014.

Hendrix, A.R., K.E. Mandt, T.K. Greathouse, K.D. Retherford, G.R. Gladstone, D.M. Hurley, P.D. Feldman, A.F. Egan, D.E. Kaufmann, P.F. Miles, J. Wm. Parker, M.W. Davis, W.R. Pryor, M.A. Bullock, S.A. Stern and N.E. Petro. "Ultraviolet Characteristics of the Lunar Compton-Belkovich Region from Lunar Reconnaissance Orbiter/Lyman Alpha Mapping Project." Presented at the 44th LPSC Conference, The Woodlands, Texas, March 2014.

Technical Staff Activities

Holloway, M., S. Mitchem and C. Reeder. "A Look at Electric Reliability Council of Texas (ERCOT's) Fast-responding Regulation Service and How It Can Stimulate the EV Market." Presented at the Center for the Commercialization of Electronic Technologies (CCET)/Husch Blackwell Webinar Series, July 2014.

Hooper, D.M. and C.L. Dinwiddie. "Subfreezing Mass Movements on Cold-climate Dunes: Examining Mars-analog Processes on Earth." Presented at the 8th International Conference on Mars, Pasadena, Calif., July 2014.

Hvass, P. "Using the ROS for Industrial Automation." Presented at the Automation Technology Expo (ATX) South Conference, Charlotte, N.C., April 2014.

Koets, M.A. "Representation and Implementation of Temporal Event Sequences (RITES): A Domain Specific Language for Precise Scheduling of Software Execution." Presented at the 2013 Workshop on Spacecraft Flight Software (FSW-13), Pasadena, Calif., December 2013.

Koets, M.A. and J. Alvarez. "Flexibility and Extensibility in the Design of Spacecraft Communications Systems." Presented at the Military Communications Conference (MILCOM 2013), San Diego, November 2013.

Koets, M.A. and M.B. Lecocke. "A Specialized Programming Language for Coordinating Software Execution Timing in Embedded Systems." Presented at the 2014 IEEE Aerospace Conference, Big Sky, Mont., March 2014.

Liljedahl, A., R. Daanen, G. Frost, G. Grosse, N. Matveyeva, M. Necsoiu, M. Raynolds, V. Romanovsky, J. Schulla and D. Walker. "Observed Pan-arctic Ice Wedge Degradation in Continuous Permafrost and Modeled Effects on Watershed-scale Hydrology." Presented at the Thermokarst Aquatic Ecosystem Workshop (THAW), Quebec City, Canada, March 2014.

Liu, Y. and S. Mitchem. "Implementation of V2G Technology Using DC Fast Charging." Presented at the 2nd Annual International Conference on Connected Vehicles & Expo (ICCVE 2013), Las Vegas, December 2013.

Mandt, K.E., O. Mousis, J.I. Lunine and D. Gautier. "Improved Constraints on the Nitrogen Isotopes in the Protosolar Nebula: Implications for the Source of the Earth's Nitrogen." Presented at the International Cometary Workshop, Toulouse, France, April 2014, and at the 44th LPSC Conference, The Woodlands, Texas, March 2014.

Mandt, K.E., T.K. Greathouse, K.D. Retherford, G.R. Gladstone, A.R. Hendrix, A.F. Egan, D.M. Hurley, P.D. Feldman, P.F. Miles and C.M. Seifert. "Evaluation of Time Variability of Water Frost in Permanently Shaded Regions Using the LRO/LAMP." Presented at the 44th LPSC Conference, The Woodlands, Texas, March 2014.

Martinez, J. "General Overview of Automated Driving." Presented at the 2014 Transportation Summit: Floridians for Better Transportation, Orlando, Fla., July 2014.

McComas, D.J. "The Interstellar Boundary Explorer (IBEX): Mission Overview and Science Results." Presented at the Space Research Centre of the Polish Academy of Sciences (SRC PAS), Warsaw, May 2014.

McConnell, M.L., M.G. Baring, P.F. Bloser, J. Greiner, A.K. Harding, D. Hartmann, J.E. Hill, P. Kaaret, R.M. Kippen, M. Pearce, N. Produit, P. Roming, J.M. Ryan, F. Ryde, T. Sakamoto, K. Toma and B. Zhang. "Polarimetry of Energetic Transients in Space (PETS) – A GRB Polarimetry Mission on the International Space Station." Presented at the AAS 13th Meeting of the High Energy Astrophysics Division (HEAD), Monterey, Calif., April 2013.

McFarland, J., B. Bichon and D. Riha. "A Probabilistic Treatment of Multiple Uncertainty Types: NASA UQ Challenge." Presented at the AIAA Science and Technology (SciTech) Forum, National Harbor, Md., January 2014.

Miller, S., R. Killough, S. Cook and C. Ruf. "Onboard Science Processing on a Microsatellite with Limited Resources." Presented at the 2014 IEEE Aerospace Conference, Big Sky, Mont., March 2014.

Mitchem, S. "Using Electric Vehicles for V2G/G2V Grid Services." Presented at the 2014 DistribuTECH Conference & Exhibition, San Antonio, January 2014.

Mitchem, S. "Utilizing Electric Vehicles for Fast Response Regulation Services." Presented at the 4th Electric Vehicles Virtual Summit, June 2014.

Mitchem, S. and M. Holloway. "Finding the Secret Sauce for Storage in the Competitive Market of ERCOT." Presented at the 4th Annual Electric Energy Storage Conference, San Diego, January 2014.

Mitchem, S. and J. Redfield. "V2G Fleet Applications." Presented at the Plug-In 2014 Conference, San Jose, Calif., July 2014.

Moneer, M. and P. Lee. "Engine Component Friction Measurements on a Single Cylinder Fired Engine." Presented at the 2014 Society of Tribologists and Lubrication Engineers (STLE) Annual Meeting, Lake Buena Vista, Fla., May 2014.

Morgan, G.A., B.A. Campbell, L.M. Carter, J.J. Plaut and N.E. Putzig. "3D Reconstruction of the Geologic Record Preserved in Amazonis Planitia Using SHARAD." Presented at the Eighth International Conference on Mars, Pasadena, Calif., July 2014.

Nixon, C., K.E. Mandt and R.D. Lorenz. "On the Age of Titan's Atmospheric Methane." Presented at the Titan Through Time Workshop 3, Laurel, Md., April 2014.

Oxley, J. "Atomization Processes." Presented at the Institute of Food Technologists (IFT) Premeeting Short Course on Microencapsulation in Food Applications, New Orleans, June 2014.

Oxley, J. "Introduction to Nanoencapsulation." Presented at the 41st Annual Meeting & Exposition of the Controlled Release Society (CRS) Nanotechnology Workshop, Chicago, July 2014.

Perry, W.D., M. Fortenberry and I.S. Smith. "TALS (Tactical Aerobotic Launch System)." Presented at the AIAA 2013 Balloon Systems Conference, Daytona Beach, Fla., March 2013.

Phelan, P. and B. Walls. "A Practical Application of a Systems Engineering Process in Space Avionics Design and Development." Presented at the 2014 IEEE Aerospace Conference, Big Sky, Mont., March 2014.

Plessis, S., D. McDougall, P. Bauman, J. Bell and K. Mandt. "Predicting and Applying Estimates of Bimolecular Diffusion in Titan's Atmosphere." Presented at the Titan Through Time Workshop 3, Laurel, Md., April 2014.

Pogorelov, N.V., S. Borovikov, R.W. Ebert, J. Heerikhuisen, S.T. Suess, M. Zhang and E. Zirnstein. "Solar Cycle Effect of the IBEX and Ulysses Measurements." Presented at the AGU Fall Meeting, San Francisco, December 2013.

Pritchard, T.A. and P. Roming. "The UV Properties of Core Collapse Supernovae." Presented at the 223rd AAS Meeting, Washington, D.C., January 2014.

Putzig, N.E., F.J. Foss II, B.A. Campbell and R.J. Phillips. "New Views of Planum Boreum Interior in a Migrated 3-D Volume of SHARAD Data." Presented at the Eighth International Conference on Mars, Pasadena, Calif., July 2014.

Reinhart, T.E. "Technologies for Medium- and Heavy-duty Truck Fuel Efficiency." Presented to the National Research Council Committee for MD and HD Vehicle Efficiency at the National Academy of Science Headquarters, Washington, D.C., April 2014.

Retherford, K.D. "Europa's Water Vapor Plumes: Discovery with Hubble Space Telescope and Changing Paradigms for the Exploration of Habitable Environments." Presented at Trinity University, San Antonio, February 2014.

Retherford, K.D., T.K. Greathouse, J.C. Cook, S.A. Stern, D.M. Hurley, G.R. Gladstone, P.D. Feldman, P.F. Miles, C. Grava, W.R. Pryor, T.J. Stubbs, D.A. Glenar, D.E. Kaufmann and the LRO/LAMP Team. "Lunar Volatile Transport in the Exosphere and from Impact Plumes: Lunar Reconnaissance Orbiter / Lyman Alpha Mapping Project (LRO/LAMP) Observing Campaigns Coordinated with Lunar Atmosphere and Dust Environment Explorer (LADEE)." Presented at the NASA Exploration Science Forum, Mountain View, Calif., July 2014.

Retherford, K.D., T.K. Greathouse, G.R. Gladstone, A.R. Hendrix, K.E. Mandt, P.F. Miles, A.F. Egan, D.E. Kaufmann, M.A. Bullock, S.A. Stern, J.Wm. Parker, M.W. Davis, P.D. Feldman, D.M. Hurley, W.R. Pryor, C. Grava, J. Mukherjee, P.O. Hayne, E. Mazarico, P. Mokashi, C.M. Seifert, P.L. Karnes, C.J. Seifert and M.H. Versteeg. "New Perspectives on the Lunar Far-UV Albedo: Implications of Lunar Reconnaissance Orbiter Lyman Alpha Mapping Project (LAMP) Results for Future Exploration." Presented at the 44th LPSC Conference, The Woodlands, Texas, March 2014.

Retherford, K.D., L. Roth, J. Saur, G.R. Gladstone, F. Nimmo, M.A. McGrath, P.D. Feldman, D.F. Strobel, T.K. Greathouse, M.W. Davis, A.J. Steffl, J.R. Spencer, F. Bagenal, L. Fletcher and the Jupiter Icy Moons Explorer-Ultraviolet Spectrograph Team. "Europa's Water Vapor Plumes: Discovery with Hubble Space Telescope and Plans for Jupiter Icy Moons Explorer-Ultraviolet Spectrograph Observations." Presented at the 44th LPSC Conference, The Woodlands, Texas, March 2014, and at the Habitability of Icy Worlds Workshop, Pasadena, Calif., February 2014.

Retherford, K.D., G.R. Gladstone, L. Roth, M.A. McGrath, J. Saur, P.D. Feldman, A.J. Steffl, D.F. Strobel, T.K. Greathouse, J.R. Spencer, F. Bagenal, L. Fletcher, J. Eterno, et al. "Europa's Atmosphere and Aurora: Recent Advances from Hubble Space Telescope (HST) Imaging Spectrograph and Plans for Plume Searches with Jupiter Icy Moons Explorer-Ultraviolet Spectrograph." Presented at the AGU Fall Meeting, San Francisco, December 2013.

Roming, P., J. De La Rosa, D.J. Whalen and A.J. Bayless. "Using the UV Lever Arm to Probe Type IIn Supernovae Shells." Presented at the 223rd AAS Meeting, Washington, D.C., January 2014.

Rose, R., W. Wells, J. Redfern, D. Rose, J. Dickinson, C. Ruf, A. Ridley and K. Nave. "NASA's Cyclone Global Navigation Satellite System (CYGNSS) Mission–Temporal Resolution of a Constellation Enabled by Micro-satellite Technology." Presented at the 27th Annual AIAA/Utah State University (USU) Conference on Small Satellites, Logan, Utah, August 2013.

Roth, L. "Hubble Space Telescope Aurora Observations:Transient Water Vapor at Europa's South Pole." Presented at the Meeting of the Committee on Astrobiology and Planetary Science (CAPS) at NRC Space Science Week, Washington, D.C., March 2014.

Roth, L., J. Saur, K.D. Retherford, P.D. Feldman, D.F. Strobel, M.A. McGrath and F. Nimmo. "Europa Plume Discovery." Presented at the Outer Planets Assessment Group (OPAG) Meeting, Tucson, Ariz., January 2014.

Roth, L., J. Saur, K.D. Retherford, P.D. Feldman, D.F. Strobel, M.A. McGrath and F. Nimmo. "Europa's Water Vapor Plumes: A Powerful Search Technique Using Hubble Space Telescope UV Aurora Observations." Presented at the Workshop on Habitability of Icy Worlds, Pasadena, Calif., February 2014.

Roth, L., J. Saur, K.D. Retherford, P.D. Feldman, D.F. Strobel, M.A. McGrath and F. Nimmo. "Hubble Space Telescope Observations of Europa's UV Aurora Morphology." Presented at the AGU Meeting, San Francisco, December 2013.

Roth, L., J. Saur, K.D. Retherford, P.D. Feldman, D.F. Strobel, M.A. McGrath and F. Nimmo. "Transient Water Vapor Plumes at Europa's South Pole." Presented at the Spring Meeting of the German Physical Society, Berlin, March 2014.

Roth, L., K.D. Retherford, J. Saur, D.F. Strobel, P.D. Feldman, M.A. McGrath and F. Nimmo. "Europa's UV Aurora: Following the Discovery of South Polar Water Vapor Plumes with Hubble Space Telescope/Space Telescope Imaging Spectrograph." Presented at the 44th LPSC Conference, The Woodlands, Texas, March 2014.

Seifert, C.M., K.E. Mandt, K.D. Retherford, T.K. Greathouse, A.R. Hendrix, A.F. Egan, G.R. Gladstone, P.D. Feldman, C. Grava and P.F. Miles. "Lunar Reconnaissance Orbiter (LRO) Lyman Alpha Mapping Project (LAMP) Investigation of the Lunar Albedo Far-UV Spectral Inversion." Presented at the 44th LPSC Conference, The Woodlands, Texas, March 2014.

Shukla, P., A. Nordquist and F. Song. "Development of Cased-pipeline Corrosion Model and Its Validation With Experimental Data." Proceedings of the National Association of Corrosion Engineers (NACE) International Annual Conference and Exposition, CORROSION 2014, San Antonio, March 2014.

Shukla, P., A. Nordquist and S. Stothoff. "Comparison of Boundary- and Finite Element-based Cathodic Protection Models." Proceedings of the NACE International Annual Conference and Exposition, CORROSION 2014, San Antonio, March 2014.

Smith, I.S. "HiSentinel & Stratospheric Airship Design Sensitivity." Presented at the Keck Institute for Science Studies Airship Workshop, Pasadena, Calif., May 2013.

Swenson, C.A. and P. Roming. "GRB Flares: A New Detection Algorithm, Previously Undetected Flares, and Implications on GRB Physics." Presented at the AAS 13th Meeting of the HEAD, Monterey, Calif., April 2013.

Swenson, C.A., P. Roming, M. de Pasquale and S. Oates. "UV/Optical and X-ray Flares in Gamma-ray Burst Light Curves." Presented at the 223rd AAS Meeting, Washington, D.C., January 2014.

Terrell, D. "Kepler 64 and Other Exoplanet Discoveries." Presented at the Small Telescopes and Astronomical Research (STAR III) Conference, Greenwood, S.C., June 2014.

Terrell, D. "Science with the Sonoita Research Observatory and the American Association of Variable Star Observers (AAVSO) Photometric All Sky Survey." Presented at the STAR III Conference, Greenwood, S.C., June 2014.

Trevino, G. "Novel Data Analytics Applications." Presented at the Texas A&M Engineering Experiment Station (TEES) Smart Grid Center, Synchrophasor and Cybersecurity Focus Groups, College Station, Texas, April 2014.

Trevino, G. "Using Electric Vehicles for Fast-response Regulation Services." Presented at the 20th Annual National Instruments (NI) Week 2014 Conference, Austin, Texas, August 2014.

Vickers, D. "Novel Data Analytics Applications." Presented at the 8th UTSA Architecture, Business, Engineering and Science Students' (ABES) Conference 2014, San Antonio, May 2014.

Walker, C., I.S. Smith and P. Goldsmith. "10 Meter Sub-orbital Large Balloon Reflector (LBR)." Presented at the 2014 IEEE Aerospace Conference, Big Sky, Mont., March 2014.

Watton, R.C., C.F. Popelar, J. McFarland, V. Bhamidipati, M.A. James, J.D. Watton, M.R. Hill, A.T. DeWald and D.L. Ball. "Predicting Fatigue Crack Growth in Forgings with Bulk Residual Stress." Presented at the USAF Aircraft Structural Integrity Program (ASIP) Conference, San Antonio, December 2014.

Technical Staff Activities

Internal Research

Funded July 1, 2014

Alvarez, J. and L. McDaniel. "Space-Based Communications Processing."

Caseres, L. and T. Mintz. "Development of a Corrosion Sensor Technology for Buried Piping."

Dannemann, K., N. Scott, A. Carpenter and S. Chocron. "Design and Development of a New Gripping System and Direct Stress Measurement Method for High Strain Rate Materials Testing."

Evans, N., T. Allison and N. Poerner. "Testing and Analysis of Acoustically Induced Vibration Stresses in Piping Systems."

Heenan, P. and G. Ragsdale. "Dynamic Transmission Conductor Measurement."

Hvass, P. "Low-Cost Safe Gears for Robots and Prosthetics."

Koets, M. and L. McDaniel. "Data Management Architectures for Gigabit Per Second, Terabit Capacity Non-Volatile Data Storage."

Livadiotis, G. "Large-Scale Quantization in Space Plasmas: Theory and Applications."

Mandt, K., G. Miller and J.-M. Jahn. "Testing of Prototype Mass Spectrometer for Earth Atmospheric Studies."

Mathis, J., S. Chocron, J. Bradley and A. Barnes. "Investigation of Computational Methods for Modeling Bird Strike Impacts on Aircraft Structures."

Ogasawara, K., S. Livi, M. Desai and N. Alexander. "Application of Solid-State Devices as Timing Detectors for Ion Time-of-Flight Measurements Around Europa."

Parvin, A., M. Dammann, M. Capps, R. Burgamy and J. Groff. "Advanced 3D Printing Techniques."

Price, W. "Investigation of Ultrasonic Pulse-Echo Measurement Techniques."

Sarlashkar, J. "Investigation of Fatigue Component in Lithium-Ion Battery Degradation Life."

Surampudi, B. and J. Steiber. "Battery Duty-Cycle Decomposition for Cycle Life Analysis."

Wileman, C. and P. Lee. "Investigation into Engine Wear Map Development with Radioactive Tracer Testing."

Patents

Alger, T.F. II and J. W. Gingrich. "EGR Control in Engine Equipped with Cylinders Having Dual Exhaust Valves." U.S. Patent No. 8,769,927. July 2014.

Branyon, D.P., K. Hoag and S. Scuderi. "Turbocharged Downsized Compression Cylinder for a Split-Cycle Engine." U.S. Patent No. 8,807,099. August 2014.

Cheruvu, N.S. and R.Wei. "Oxidation Resistant Nanocrystalline MCRAL(Y) Coatings and Methods of Forming Such Coatings." U.S. Patent No. 8,790,791. July 2014.

Gordon, C.R., C. Harbold and H. Hanson. "Method of Inserting an Expandable Intervertebral Implant without Overdistraction." U.S. Patent No. 8,753,398. June 2014.

Luce, D.K., S. Wirth, A.J. Massey and C.A. Parrot. "Methods for Manipulating Cutting Elements for Earth-Boring Drill Bits and Tools." U.S. Patent No. 8,731,717. May 2014.

McHardy, S.F., R.M. Corbett, D.M. Maxwell, M.W. Tidwell, B. Campos and C. J. Bemben. "Oximes for Treatment of Peripheral and Central Nervous System Exposure to Acetyl Cholinesterase Inhibitors." U.S. Patent No. 8,772,345. July 2014.

Moore, J.J., A. Lerche and B. Moreland. "Internally-Cooled Centrifugal Compressor with Cooling Jacket Formed in the Diaphragm." U.S. Patent No. 8,814,509. August 2014.

Nored, M.G., K. Brun and D.M. Deffenbaugh. "Pressure Recovery Insert for Reciprocating Gas Compressor." U.S. Patent No. 8,740,581. June 2014.

Smolik, M.A., D.B. Kramer and T.L. Haby. "System and Method for Sampling Fluid from Piston Top Land Crevice of Piston Engine." U.S. Patent No. 8,807,110. August 2014.

Unruh, J.H. "Hyperbolic Horn for Pulsation Filter Device Used With Gas Compressor." U.S. Patent No. 8,740,590. June 2014.

VanDyne, E., J.W. Brown, F. Schumacher and C.J. Chadwell. "Super-turbocharger Control Systems." U.S. Patent No. 8,769,949. July 2014.

Wei, Q. and I.S. Abdul-Khalek. "Apparatus and Methods for Determination of Total and Solid Carbon Content of Engine Exhaust." U.S. Patent No. 8,783,090. July 2014.

Wei, R., R.L. Johnson, C. Rincon and M.A. Miller. "Method for Plasma Immersion Ion Processing and Depositing Coating in Hollow Substrates Using a Heated Center Electrode." U.S. Patent No. 8,753,725. June 2014.

Wei, R., E. Langa and S.L. Lee. "Apparatus and Method Utilizing a Double Glow Discharge Plasma for Sputter Cleaning." U.S. Patent No. 8,747,631. June 2014.

Zoss, J.K., T.E. Lyons Jr. and R.L. Simmons. "Methods for Manipulating Cutting Elements for Earth-Boring Drill Bits and Tools." U.S. Patent No. 8,731,717. May 2014.

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- **ITS 3C Summit,** Mobile, Ala.; September 14-17, 2014
- **IEEE AUTOTESTCON,** St. Louis, Mo.; September 15-18, 2014
- **ASGMT**, Houston; September 22-25, 2014
- **43rd Turbomachinery and 30th Pump Symposia,** Houston; September 22-25, 2014
- **Accelerate CO: Advancing Colorado's Innovation Symposium,** Loveland, Colo.; October 1-3, 2014
- **Algae Biomass Summit,** San Diego; September 29-October 2, 2014
- **65th International Astronautical Congress 2014**, Toronto; September 29-October 3, 2014
- **HHP (High Horsepower) Summit,** New Orleans; October 7-9, 2014
- **6th AIChE Southwest Process Technology Conference,** Galveston, Texas; October 9-10, 2014
- **PODD: Partnership Opportunities in Drug Deliveries,** Boston; October 14-15, 2014
- **RoboBusiness,** Boston; October 15-17, 2014
- **NACE Northern Area Eastern Conference,** St. John's, Newfoundland, Canada; October 19-21, 2014
- **International Telemetering Conference/USA (ITC/USA),** San Diego; October 20-23, 2014
- **ASNT Annual Conference,** Charleston, S.C.; October 27-30, 2014
- **Automotive Testing Expo 2014 North American,** Novi, Mich.; October 28-30, 2014
- **DMC (Defense Manufacturing Conference) 2014**, San Antonio; December 1-4, 2014
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