National Aeronautics and Space Administration

THE NEIL A. ARMSTRONG FLIGHT RESEARCH CENTER

# X-PRESS

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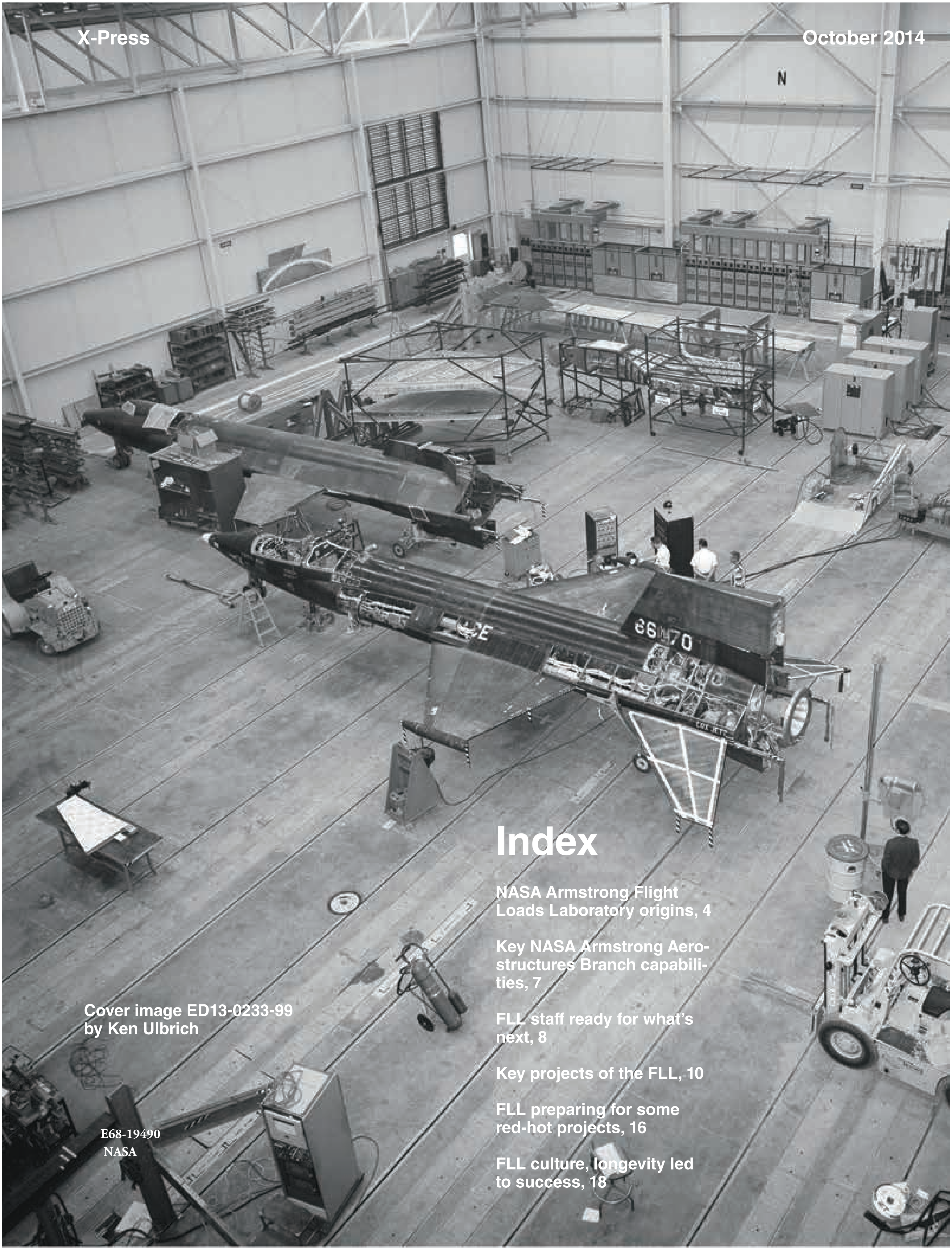
# Flight Loads Lab at 50

## Ready for the future, respectful of its history




Cover image ED13-0233-99 by Ken Ulbrich

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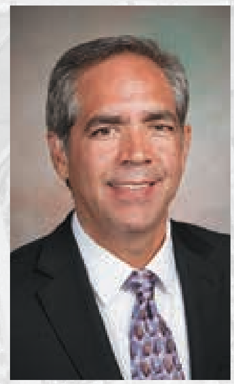
# 50 years

## Armstrong Flight Loads Laboratory poised for another amazing 50 years



**David McBride**
Director, NASA Armstrong Flight Research Center

Congratulations to the men and women of the Flight Loads Laboratory, or FLL, for more than 50 years of excellence.

This anniversary is a time to reflect on the major projects that have come through the FLL and the men and women that helped these projects to succeed. From the X-15 and YF-12 of the early years to more modern marvels such as the Adaptive Compliant Trailing Edge flight experiment and the Hypersonic Inflatable Aerodynamic Decelerator, with dozens of major accomplishments in between, the highly skilled FLL staff is positioned for the future.

We have had a great set of mentors who have passed on what they know to each fledgling generation. When I visit the loads lab, I see new projects and people, but the same commitment to the work and completing it safely – a contributing factor to the FLL continuing to be a world-class research facility.

The Flight Loads Laboratory is a place where every aircraft flight experiment at some point in its research and development has gone for instrumentation and ground testing of its airframe and components. The FLL has been a necessary element of the work we have accomplished for five decades.

One of the most unusual aspects of the FLL is its unique thermal test capability to cool and heat flight structures from -320 to 3,000 degrees Fahrenheit. Mechanical loading in a heated environment in air or in an oxygen-free one is a rare capability.

It is a full-spectrum test lab that has sought to understand everything from sensors measuring flight loads to understanding the effect of flight loads (static, dynamic and thermal) on a variety of flight vehicles. Some of those flight vehicles included everything from conventional aircraft to high-speed aircraft like the SR-71 and YF-12 to re-entry vehicles like the X-37 space plane. Over the years the lab has also sought to understand the structural performance of a wide range of materials including conventional aircraft materials to exotic materials like metal matrix composites, carbon-carbon and now shape memory alloys.

The size of the FLL is a capability that allows for testing full-scale aircraft through the years. We have tested aircraft as big as the AeroVironment Global Observer that had a 175-foot wingspan to an E-2C Hawkeye for the Navy. The laboratory's floor space has also allowed multiple large-scale test efforts to run simultaneously.

The FLL's capabilities and innovative workforce have also enabled the development of new technologies, like the fiber optic strain sensing and shape sensing technologies that have recently received a lot of visibility and acclaim. We have led the way in strain gauge measurements, applications and calibration and are continually working to prepare for the next generation of structural sensing requirements.

Developing and validating loads equations through ground tests of components and aircraft before flight helps limit risks and build a foundation for successful flight projects. The value of understanding gained from the ground test of any vehicle, or any article, how it works and how it fails structurally before it's taken to a true flight condition cannot be underestimated.

The FLL has proved its value with accomplishments for just about every research and test vehicle that has ever come through the center. A lot of aircraft were designed and built with the notion that they would not need a laboratory like the FLL to validate their systems and structures. However, history has shown that the utility and efficiency of ground testing and the value of research that comes out of flight is enhanced by having the loads lab available.

I invite people who don't get a chance to see the FLL to schedule a visit – the team is excited to talk about what they do. Coordinate your visit with Larry Hudson at ext. 3925 and observe the safety rules.

The FLL has successfully supported the center, NASA and the nation for 50 years and the way the loads lab and its dedicated staff benefits the flight research we do, the lab will continue to have an impact for the next 50 years.


E67-17266 NASA

# FLL Origins

## X-15 and SR-71 rocketed the lab into existence, but projects keep it on edge of technology

***Editor's note:*** *NASA Armstrong Historian Christian Gelzer is writing a book on the NASA Armstrong Flight Loads Laboratory to commemorate its 50th anniversary. He provided a brief overview of some of the facility's key moments for the NASA Armstrong X-Press.*

**By Christian Gelzer**
NASA Armstrong historian

What is now known as the NASA Armstrong Flight Loads Laboratory, or FLL, had its start in 1964 when it became clear that special facilities would be needed to test the latest in aerospace technology. It was known as the High Temperature Loads Calibration Laboratory at a time the center was named the NASA Flight Research Center.

In particular, the X-15 required aero-thermo-structural testing related to hypersonic flight that presented new challenges. When the experimental rocket plane began flying, the center established the Heat Facility in an earlier iteration, located in a corner of the Loads Calibration Hangar, or what today is known as Hangar 4801.

That facility was insufficient to meet the demands of the X-15 that flew at hypersonic speeds, which generated extraordinary temperatures, dynamic loads and mechanical stresses. A stand-alone facility had to be established to meet the new requirements and challenges that arose from this unforgiving region of flight.

Since then, the FLL's work is at times mesmerizing, like the warm glow of extreme heating tests, or research into the ultimate limits of a wing's strength. Each test is conducted to add to the aeronautical modeling databases, validate aircraft and spacecraft parts and structures and verify that conclusions derived from past research apply as expected and in a manner that reduces risk to the research vehicle and the pilots who fly them.

An example is the loads calibration and thermal testing work in the 1970s that required the entire airframe of the YF-12 to be

E65-134946 NASA

***Above,*** *the construction of the NASA Armstrong Flight Loads Laboratory was started in 1964 and was concluded in 1965. This image shows some of the construction.* ***At left****, the X-15 is prepared for a loads calibration test of its horizontal stabilizer.*

EC97-44165-69 NASA/Carla Thomas

*This is how the modern NASA Armstrong Flight Loads Laboratory looks as of 1997. The significant changes since have happened to the inside of the facility.*

EC80-12358 NASA

*Gary Craton works on a data management system.*

EC80-12363 NASA

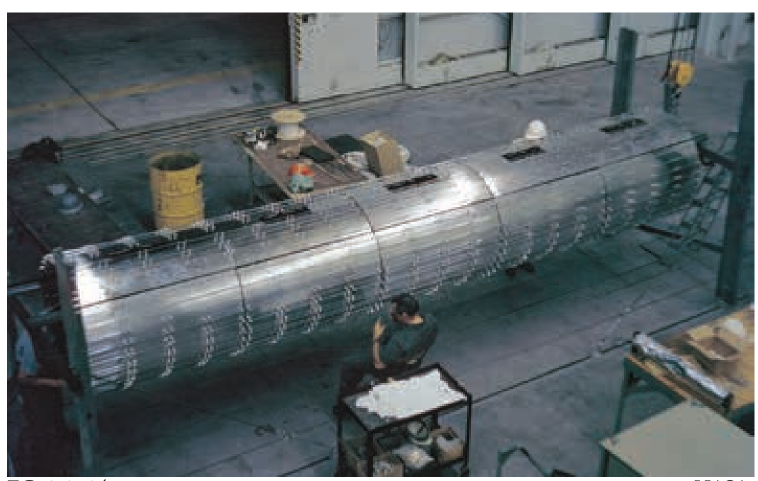
*Larry Reardon works on a load control system.*

EC81-16138 NASA

*This picture shows FLL staff in 1981. From left are Roger Fields, Del Berg, Carl Barnes, Yoshio Ekimoto, Leon Hatcher and Gary Craton.*

EC99-45302-02 NASA/Tony Landis

*Van Fleischer (then Van Tran) prepared a data acquisition system for test.*



EC73-3724 NASA

*This photo shows the radiant heating system for the YF-12 engine bay.*

tested at the same temperatures it encountered in flight at Mach 3. The spectacular glow was one of many aspects of the research that resulted in enhanced flight safety.

The laboratory's experience with hypersonic and supersonic test and calibration led to work on another of NASA's mainstay programs – the space shuttles. Study was needed on the shuttle's elevon seals and convective heating that occurred during reentry. The validation and verification work completed at the lab provided recommendations and confidence that the seals would be effective when it mattered most and added to mission safety and success.

The laboratory's greatest asset – its people – came into focus again with the arrival of the Hypersonic Wing Test Structure, also in the 1980s. That research required the laboratory to test a hot structure wing concept consisting of tubular panels made of Rene 41 to 1,900 degrees Fahrenheit, while being loaded.

The FLL again had a critical role during the National Aero-Space Plane, or NASP, program. The laboratory performed the first combined heating and loading tests of Titanium Matrix Composites, or TMC, structural panels for the X-30. While the X-30 wasn't built, the information gathered through the work here provides the tools for designers of the future to develop such a vehicle.

The laboratory's research can have implications for the future, but sometimes it can just help solve a new challenge. An example is loads calibration tests on the F-15 Advanced Control Technology for Integrated Vehicles, or ACTIVE, engine mounts.

The tests provided the first successful measurement of engine thrust with instrumented engine mount links. A vectored thrust loads measurement was not originally included in the project plan, but was added when it became clear that it was needed. As a result, Bob Sims, an aerosturctures engineer, found a successful way to measure the vectored thrust loads that assured a successful flight program.

Many times FLL projects set high water marks. The Active Aeroelastic Wing, or AAW, F/A-18 – also known as the X-53 – set several lab records during its strain gauge load calibration test. First, the peak load was the largest applied to any aircraft in the lab. The equivalent of a 5 *g* flight load was applied to the aircraft, or the equivalent of lifting five F/A-18s off of the floor.

A wide variety of load distributions were applied to this aircraft – 68 load sets in total – simulating a large portion of the flight load envelope. To do this, test hardware was employed that could simultaneously apply load through 32 independent load zones into a total of 102 bonded load pads using whiffle trees. A whiffle tree is a load distribution linkage assembly that connects multiple load pads to a single hydraulic cylinder. The aircraft data recorded during this test included 200 strain gauge channels. The AAW strain gauge load calibration test was the most extensive room temperature load calibration test performed on an aircraft in the FLL.

The tests were key to the aircraft

FLL History, page 8

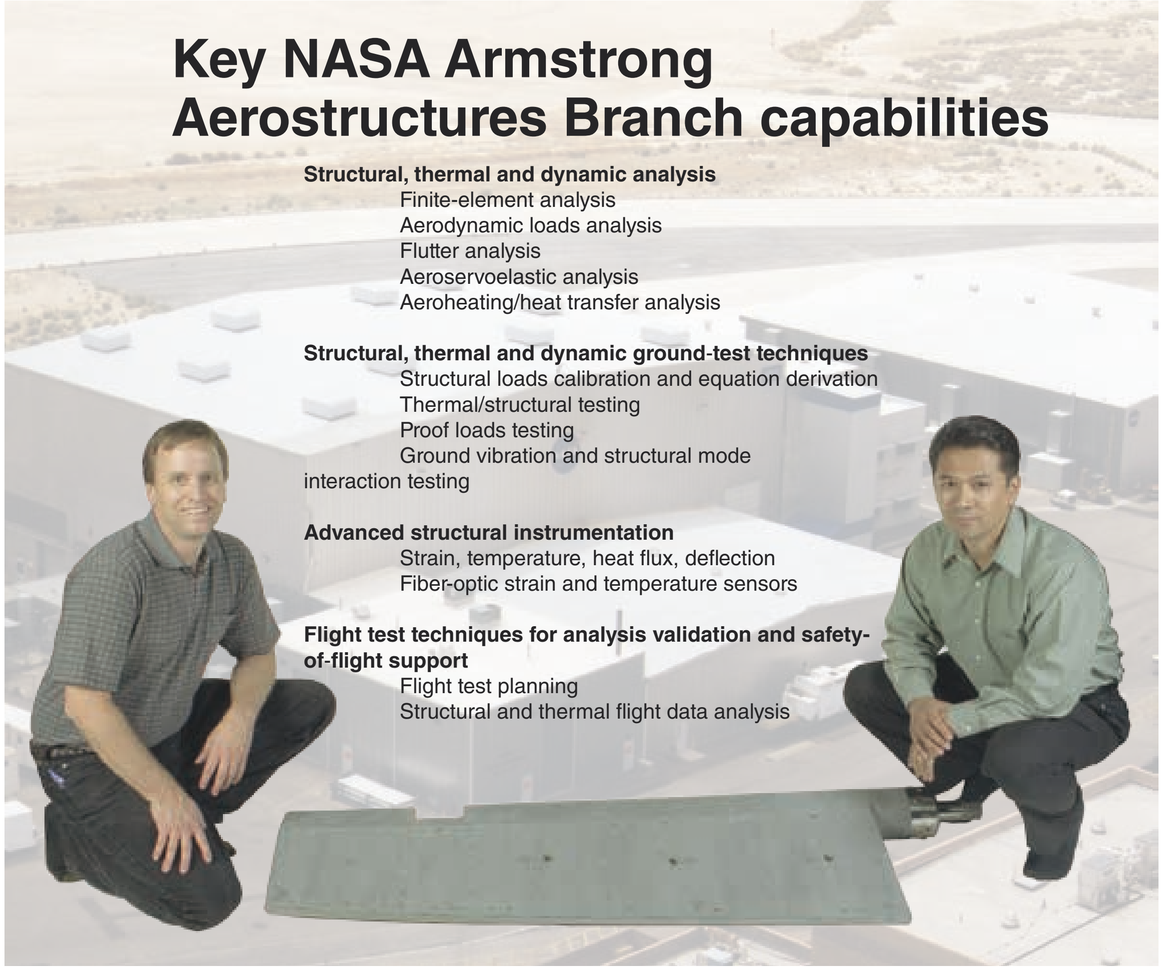
## Key NASA Armstrong Aerostructures Branch capabilities

**Structural, thermal and dynamic analysis**
- Finite-element analysis
- Aerodynamic loads analysis
- Flutter analysis
- Aeroservoelastic analysis
- Aeroheating/heat transfer analysis

**Structural, thermal and dynamic ground-test techniques**
- Structural loads calibration and equation derivation
- Thermal/structural testing
- Proof loads testing
- Ground vibration and structural mode interaction testing

**Advanced structural instrumentation**
- Strain, temperature, heat flux, deflection
- Fiber-optic strain and temperature sensors

**Flight test techniques for analysis validation and safety-of-flight support**
- Flight test planning
- Structural and thermal flight data analysis



ED05-0120-1 NASA

*Craig Stephens, left, and Larry Hudson show the X-37 elevon tested in the FLL.*

EC95-43136-02 NASA

*The load calibration test on the F-15 Advanced Control Technology for Integrated Vehicles, or ACTIVE, engine mounts was an important FLL project.*

# FLL history... from page 7

taking flight. The series of test flights validated wing warping, or wing twist, could be used for roll control of an aircraft. The concepts originated with the Wright brothers, who employed wing twist to control the first flyer.

Between 2001 and 2004 the laboratory performed the first thermal-mechanical qualification test of a flight designed carbon-carbon hot-structure control surface, a flaperon, for use on the X-37 space plane. That research involved extensive use of high-temperature fiber-optic strain sensors. The FLL has been directly involved with expanding the use of fiber optic strain sensing technology to the testing of high-temperature composite structures and enabling the understanding of structural performance in relevant high-temperature environments. It was during this test period that the lab expanded its high-temperature limit to beyond 2,500 degrees F.

The FLL staff members have their vision set on keeping atop the latest developments in materials as well. In partnership with NASA's Glenn Research Center in Cleveland, the laboratory is working to develop flight application for shape memory alloys, which are a class of metals that exhibit the ability to change shape with the application of heat.

Using these new materials could potentially enhance safety and reduce maintenance of future actuators, or be used in a new generation of aircraft wings that can change their shape to better maximize aerodynamic forces and fuel consumption.

The laboratory has been working to develop techniques to measure strains on highly elastic materials using a sensor technique developed for the medical industry. NASA researcher Anthony "Nino" Piazza worked with a company to modify those sensors to create a sensor suitable for making strain measurements on such research projects as NASA Langley Research Center's Hypersonic Inflatable Aerodynamic Decelerator, or HIAD, on which the Hampton, Virginia, laboratory recently concluded work.

The FLL is an asset not only for the center, but also for the agency and the nation. The extraordinary assembly of people, skills and capabilities exist in very few places. Industry also is a regular partner, asking for help on myriad projects such as the shuttle elevon seal test and X-37 work previously mentioned. Another is the load testing of the AeroVironment Global Observer Wing; the first large-scale loads test that employed distributed strain sensing via optical fibers.

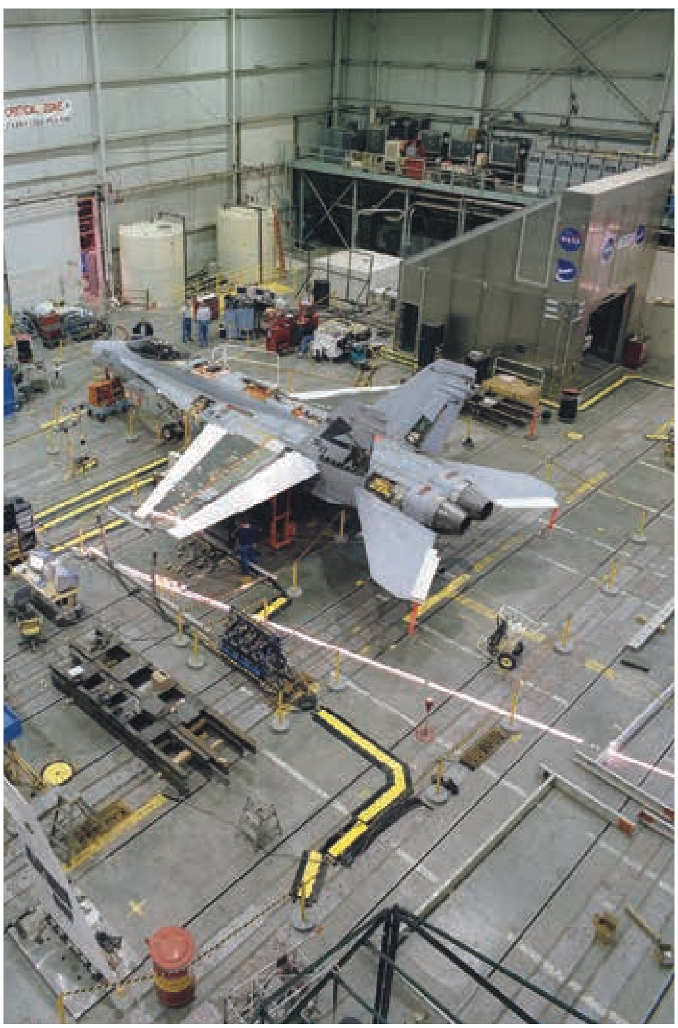
Federal government branches have come to the laboratory as well, including the U.S. Navy in 2004-5 with an E-2C Hawkeye. The Navy required advanced and thorough loads testing of the aircraft wings prior to major modifications to the Hawkeye fleet. Ironically, the laboratory is better known outside of Armstrong than it is within the center: its work, its value and its reputation radiate widely.

The FLL's work melds research and support of safety into a constant pursuit of understanding the latest technology developments in aerospace and ensuring that aircraft complete their missions safely. Often, these two go together seamlessly.


EC04-0360-75 NASA/Tony Landis

***At left**, the E-2C Hawkeye was the largest non-NASA aircraft that went through a loads calibration test in the FLL. Testing incorporated the effect of engine loads into the calibration.*

***Below**, the Active Aeroelastic Wing featured the largest number of loads control channels ever used during a loads calibration test in the FLL. More than 32 channels were used for load testing that included up, down and torsion loading.*



EC01-0112-72 NASA/Tom Tschida


ED14-0095-128 NASA/Ken Ulbrich

*NASA's G-III No. 804 test bed rests on three pneumatic lifting devices or "airbags" in preparation for loads testing in NASA Armstrong's Flight Loads Lab.*

# Eye on the Future

## FLL staff ready for what's next

**By Jay Levine**
X-Press editor

When the Adaptive Compliant Trailing Edge, or ACTE, project came to NASA Armstrong Flight Research Center's Flight Loads Laboratory, it came with a rather unique set of requirements.

NASA's Gulfstream III No. 804 aircraft is the project's test bed and had new flaps installed, which required a wing loads calibration. Structural engineers had some unusual findings earlier in the testing that were the result of the main landing gear's proximity to the inboard strain gauges. Engineers determined having the aircraft off of the ground was the best way to reduce the influence of the landing gear on obtaining good data.

Enter innovative thinking. For more than 50 years the FLL staff has respected and been aware of its past, but has always looked for new ways to solve the latest challenges. The answer the research team devised for gaining the data – three large inflatable airbags.

"If we had not used the airbags, we would have had to support the aircraft some other way off of the main gear," said Bill Lokos, a long-time center structures engineer. "We could have put slings around the fuselage and lifted it with a crane, or we could have designed and fabricated a cradle to hold the fuselage, but the G-III fuselage is not something I wanted to put in a cradle."

The answer became clear.

"Airbags have been used to recover airplanes that have collapsed landing gear as an alternative to using a crane to lift them up following an accident," Lokos said. "The more I thought about the airbags and the more I researched them, the more I thought this was the right approach. The airbags were a very friendly and low-cost way to support the airplane off the main gear while we loaded the wing."

The load limits of the airbags and

ED14-0095-161 NASA/Ken Ulbrich

*Two of three inflatable bags used to lift NASA's G-III during loads testing were positioned under the wing root area; the third under the rear fuselage. With an operating pressure of only 3.5 psi, each airbag is capable of supporting 12 tons.*

the need to constantly replenish the air leaking from the air bags in order to maintain the aircraft at the correct height for an hour or longer were key challenges, Lokos said. The loading hardware and the airbags requirements overlapped to complete the test and gather all the required information.

Ron Haraguchi, test operation manager, diffused airbag leakage concerns with a redesign of the airbag controls. He also built the three pneumatic control manifolds.

"We were able to load the wings hydraulically once the airplane was properly supported," Lokos explained.

"We had good data, thanks to Ron, and the combination of (pressure systems manager) Richard Wong's advice about airbag safety features, senior hydraulic control system technician Dave Neufeld's hydraulic loading and Larry Hudson's checklist and procedures enabled different dynamics and test overlap to produce the data," Lokos said.

Combining known loads with strain-gauge responses in the lab helps researchers develop a database for validating or correcting load equations, Lokos said. Net structural loads are the sum of the forces acting on the aircraft in flight and these are what the load equations are created to calculate.

Evaluation of the revolutionary new ACTE flap system is a joint effort of NASA Armstrong and the U.S. Air Force Research Laboratory. The advanced trailing-edge wing flap has the potential to improve aircraft aerodynamics and fuel-use efficiency and reduce airport-area noise generated during takeoff and landing.

**New materials**

Being aware of the latest ideas and preparing the laboratory for maximizing its use is a hallmark of the FLL. That was one of many items that Tom Horn, who was a cooperative education student in 1985, learned from one of his first mentors – Lokos.

Horn later was the Aerostructures Branch chief for nearly a decade. During his tenure Horn looked to enhance the FLL's research content and with an eye to the future began three years of looking for information about technology developments centered on shape memory alloys, or SMAs.

In this case, Horn saw the new alloy as the next revolution in materials and began to ask more about it to properly prepare the lab. Matthew Moholt, a NASA Armstrong research engineer, then was asked to familiarize himself with the new material and how it may be used in future aerospace projects.



ED08-0230-329 NASA/Tony Landis

*This moment of inertia test with the Orion Crew Exploration Vehicle is similar to the tests that are expected on the Dream Chaser when it returns to NASA Armstrong toward the end of 2014.*

At first, the shape memory alloys appeared to Moholt as a dark art. The engineering behind SMAs seemed like a mystery. That ended when he visited NASA's Glenn Research Center in Cleveland, where researchers are developing the SMA material, he said. Moholt soon learned more about the SMAs that have the ability to change shape with the application of heat.

While NASA Glenn continues to develop the material, Moholt was able to convince NASA Armstrong Center Innovation Fund reviewers to award a small grant to look at a smart structure made of SMAs. Now with Aeronautics Research Mission Directorate funding, the idea could take flight on a subscale aircraft as soon as 2016, Moholt said.

SMA material will be used for a set of reconfigurable wings for the remotely piloted/autonomous subscale Prototype Technology Evaluation Research Aircraft, or PTERA, he explained. Ground tests could begin as soon as 2015.

"Throw all the old paradigms out the window," he added. "There is a lot of interest out there. Industry is looking at the potential benefit of these new materials."

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# Future... from page 10

**Dream Chaser**

Another upcoming FLL project features a returning customer – the Sierra Nevada Corporation and its Dream Chaser flight test vehicle.

The Dream Chaser successfully completed captive carry and free-flight research at NASA Armstrong in 2013 and now the same vehicle is coming back for additional research. The Dream Chaser was a part of NASA's Commercial Crew Program and although it was not selected in the latest round of announcements by NASA for further funding, the company is pursuing international customers.

The vehicle is expected to arrive at NASA Armstrong in early 2015 for a series of tests that will help validate equations and models that will be used for designing Dream Chaser flight controls.

"The moments and products of inertia help us to determine how much of the mass is distributed away from the center of gravity. The dynamics and controls engineers use that information to understand how to control the vehicle," said Andrew Holguin, the lead test engineer for the moment of inertia testing. "The test method employed consists of swinging the vehicle as a compound pendulum."

How to conduct the research has been determined.

"The Dream Chaser will be suspended underneath a test fixture and will be swinging about three different axes to acquire data to calculate the three moments of inertia," Holguin explained. "We also plan to tilt the aircraft pitch up and pitch down to get the data necessary for calculation of one of the products of inertia."

The test fixture is unique to the FLL and is the same one used to research the Crew Exploration Vehicle in 2008. Challenges for the research that is expected to last a few weeks include management of the loads, which will be high with the weight of a full-size vehicle, moving the vehicle into the different test configurations, and designing hardware that will get the job done efficiently.

**Fiber Optic Strain Sensing technology**

Another loads lab innovation is seen in the Fiber Optic Strain Sensing, or FOSS, system first developed at NASA's Langley Research Center in Hampton, Virginia, but matured into a patented technology by a team of researchers at NASA Armstrong including Lance Richards, Allen Parker, William "Bill" Ko and Anthony "Nino" Piazza.

NASA Armstrong fiber optics sensing work is out of this world. The NASA Armstrong FOSS team has developed sensing hardware and algorithms to a technology readiness level that it is useful not only on Earth, but also for at least two space or near-space vehicle projects.

A Space Act Agreement with Virgin Galactic will have NASA Armstrong engineers and technicians heading up an effort to help the company instrument the White Knight II vehicle to measure strain along the wings and center section. Use of fiber optic sensing technology could help the company to make special strain and deflection measurements while at the same time gaining confidence in the technology for possible future flight applications, said center researcher Allen Parker.

Another application for the fiber optics sensing technology is an effort funded by Kennedy Space Center in Florida. The concept is to use the technology on an expendable launch vehicle. The multi-center effort also relies on a partnership NASA Armstrong is developing with NASA's Marshall Space Center, Huntsville, Alabama, to determine how to integrate the fiber optic sensors onto a rocket on which the sensing system could be ready for testing by the end of the year, Parker said.

"The fibers are capable of wide temperature ranges. The system has to operate from launch to space and stream data off for a few hours once it is in space. The biggest challenge is to survive the dynamic launch environment. We have a few ideas and we are fortunate to work with Marshall engineers, who do this day in and day out," he added.

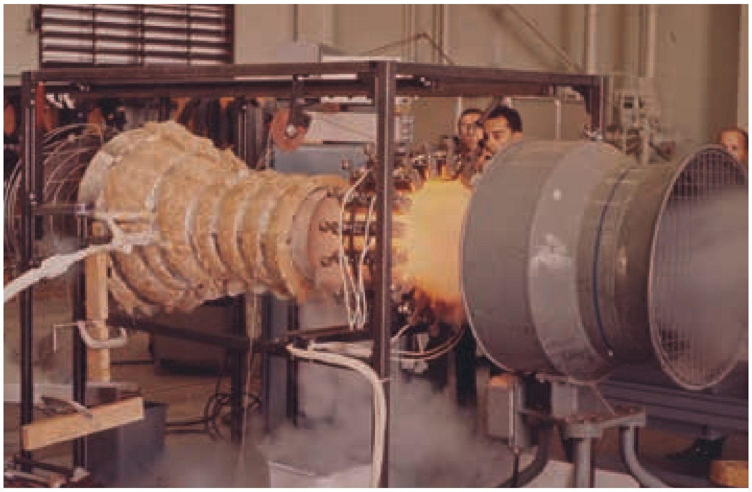
ED08-0109-07 NASA/Tom Tschida

*The fiber-optic shape sensing, or FOSS, system was originally flight tested on NASA Armstrong's Ikhana aircraft. Clockwise from left, Anthony "Nino" Piazza, Allen Parker, William Ko and Lance Richards installed the system. The center's current fiber optic team won the R&D100 award for their work, the equivalent of the Oscars of technology.*

ED13-0300-02 NASA/Carla Thomas

*The Sierra Nevada Corporation Dream Chaser, seen here in a captive carry flight in 2013, is expected to return for moment of inertia ground tests.*

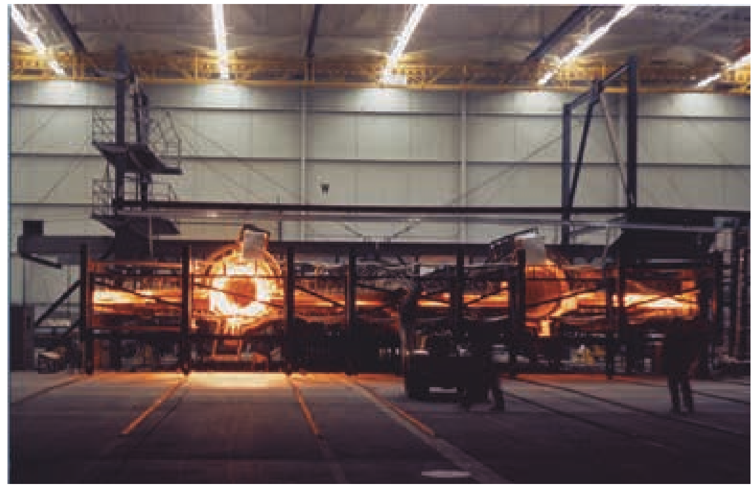
# Key projects
## of the NASA Armstrong FLL



EC66-1449 NASA

## X-15 thermal testing

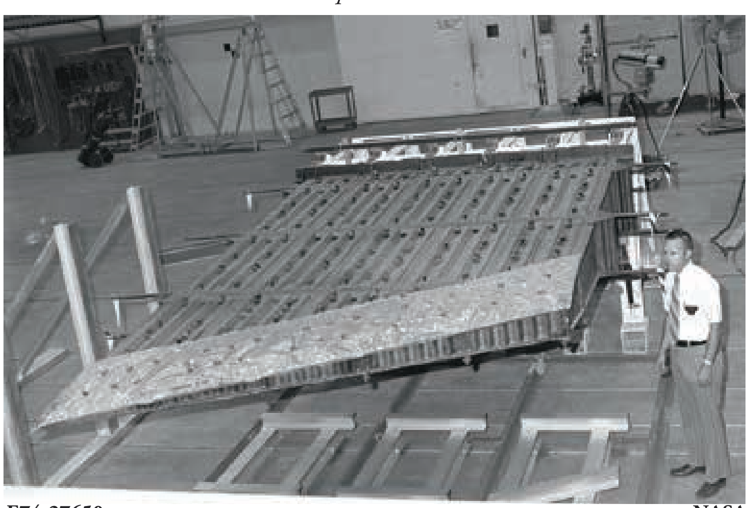
*The rocket-powered X-15 solar probe flight simulator test was in 1966 for NASA's Jet Propulsion Laboratory in Pasadena, California. X-15 components were among the first heating tests performed in the Flight Loads Laboratory. X-15 tests helped researchers understand and quantify the effects of aerodynamic heating on hypersonic aircraft structures. The X-15 was instrumental to thermostructural test and development at the center.*



EC73-3708 NASA

## YF-12 hot loads calibration

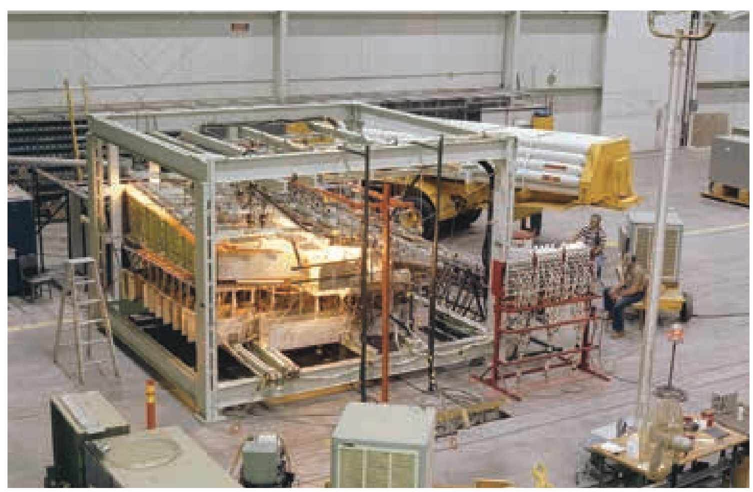
*The triple-supersonic aircraft had mechanical loading and heating tests in the FLL. The YF-12 remains the only full-vehicle thermal test ever performed at the center and the only heating test performed on the aircraft. It helped researchers understand and quantify the effects heating had on strain gauge instrumentation during heating of an aircraft to Mach 3 cruise conditions.*



E74-27650 NASA

## HWTS

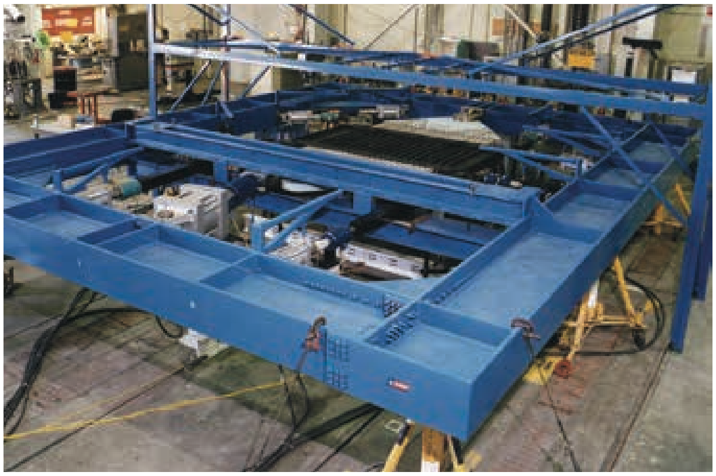
*The decade-long Hypersonic Wing Test Structure, or HWTS, test program featured the first combined heating and mechanical loading tests at the center. It also was the first application of weldable and capacitive strain gauge measurement techniques to record strains during a Mach 5 thermal simulation. It also was the first heating test of an advanced hypersonic wing structure. The HWTS used tubular panels made of Rene 41, an exotic nickel based alloy. Test temperatures reached 1,900 degrees Fahrenheit.*



EC79-11287 NASA

## Space shuttle elevon seals

*The FLL applied mechanical loads and heat to a portion of the orbiter wing and elevon. The seals were designed to prevent free stream air from entering the gap between the aluminum wing structure and the elevons during movement of the control surfaces. The free stream air temperature at atmospheric entry speeds greatly exceeds the melting point of the aluminum wing structure and the seals were essential to prevent air from entering this gap and causing structural failure. The FLL tests verified the design.*



EC94-42663-1 NASA

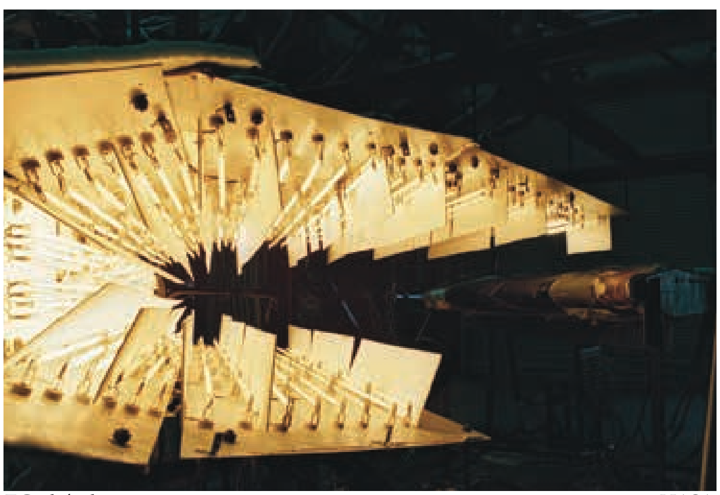
EC95-43125-9 NASA

## TMC side shear panel test

*A fuselage panel called the Titanium Matrix Composite, or TMC, side-shear panel has the distinction of having the highest mechanical loads applied to a structure while it was being heated. The tests were intended to demonstrate aerospace plane technology for the X-30 program. The panel was loaded bi-axially to 100 percent of its design load limit of 60,000 pounds shear and 240,000 pounds axial tension, while being heated to 500 degrees F. While the X-30 wasn't built, the information gathered through the work here provided the tools for designers of the future to develop such a vehicle.*

## F-15 ACTIVE calibration

*The F-15 Advanced Control Technology for Integrated Vehicles, or ACTIVE, vectored thrust load calibration tests are an example of how the FLL can solve problems. The test marked the first successful measurement of engine thrust with instrumented engine mount links. A vectored thrust loads measurement was not originally included in the project plan, but was added when it became clear that it was needed. As a result an aerosturctures engineer found a successful way to accurately measure the vectored thrust loads in an elevated temperature environment that assured a successful flight program.*



EC96-43635-02 NASA

EC01-249-06 NASA/Tom Tschida

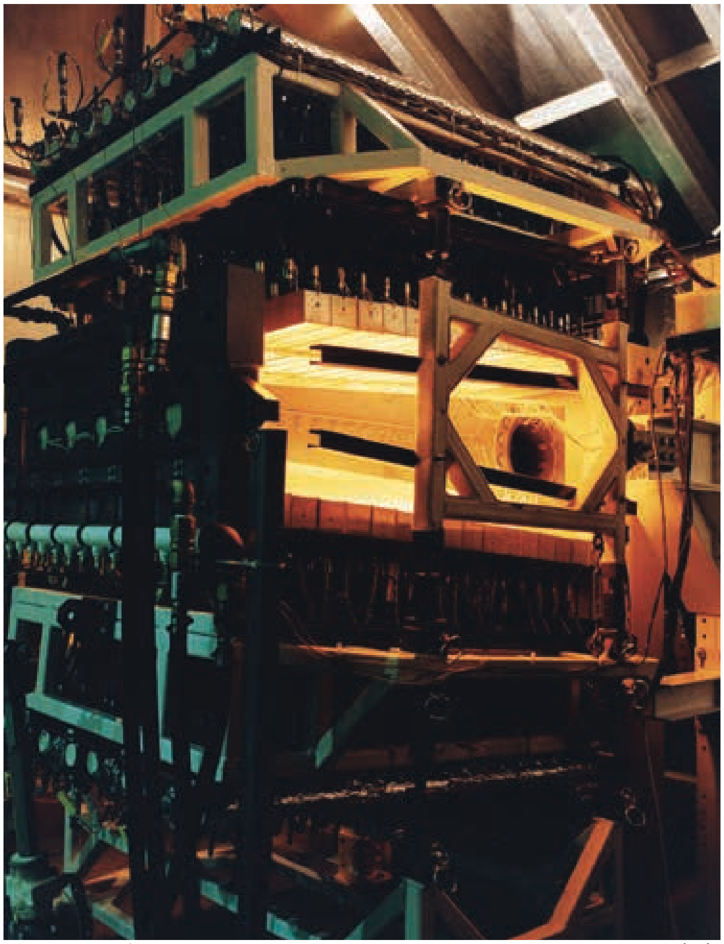
## PHYSX thermal test

*The Pegasus Hypersonic Experiment, or PHYSX, wing glove project demonstrated the overall strengths of the Aerostructures Branch and the FLL from structural design to test execution. The wing glove was tested to a Mach 8 thermal simulation. Thermal analysis was an integral part of developing the technique to successfully perform the heating test. The tests also demonstrated the effectiveness of the unique design of the wing glove attachment method.* ***Note*** *– the tests required pre-cooling to -60 degrees F to simulate launch conditions prior to heating.*

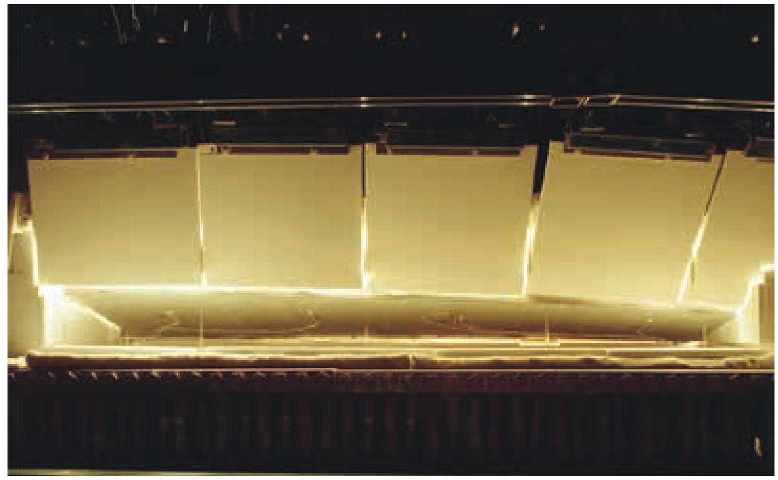
## AAW loads calibration

*The Active Aeroelastic Wing F/A-18, also known as the X-53, set several lab records during its strain gage load calibration test. First, the peak load was the largest applied to any aircraft tested in the lab. The equivalent of a 5 g flight load was applied to the aircraft, or the equivalent of lifting five F/A-18s off of the floor. The aircraft data recorded during this test included 200 strain gage channels. The AAW strain gage load calibration test was the most extensive room temperature load calibration test performed on an aircraft in the FLL. The tests were key to the aircraft taking flight.*

**Editor's note: The NASA Armstrong Flight Loads Laboratory personnel developed this list to recognize some of the lab's most outstanding accomplishments.**



EC02-0255-16 NASA/Tom Tschida



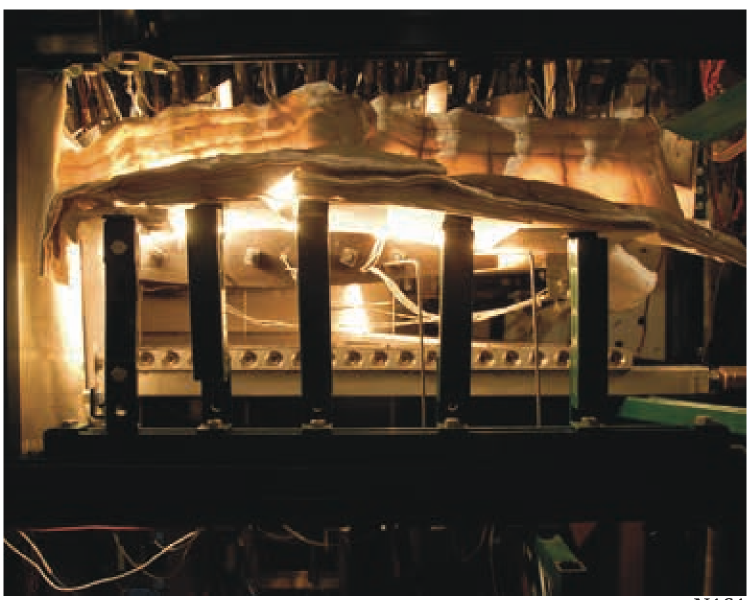
EC05-0183-3 NASA

# X-37 flaperon qualification unit

***Above***, *the X-37 flaperon qualification unit test was the first ever thermal-mechanical qualification test of a carbon-carbon hot-structure control surface designed for space flight. This test qualified carbon-carbon flaperons for use on the X-37 space plane and also featured extensive use of high-temperature fiber-optic strain sensors. Peak temperatures reached 2,500 degrees F.*

# Carbon-carbon control surface

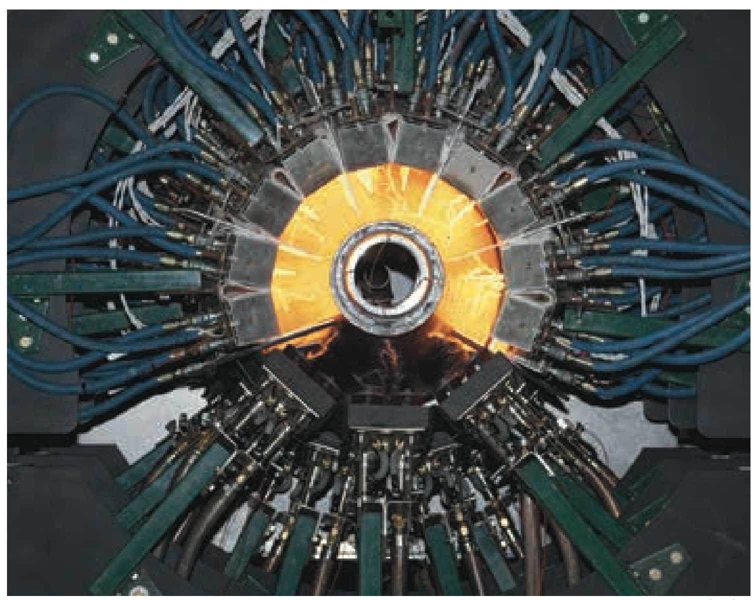
***At left***, *is the first combined heating and loading of a flight-weight designed carbon-carbon hot-structure control surface. The test article was heated to 2,000 degrees F on upper and lower surfaces, while it was simultaneously loaded to 100 percent of its design limit load. This also marked the first application of high-temperature fiber-optic sensors on a hot structure and also was the first large-scale test article ever heated in an inert atmosphere in the FLL.*



NASA

# C-SiC ruddervator

*The most extensive thermal-structural test performed on a carbon-silicon-carbide, or C-SiC, hot-structure control surface was during the C-SiC ruddervator subcomponent test. Testing involved simultaneous loading and heating at reentry and trans-atmospheric hypersonic cruise conditions. Testing also included room-temperature load testing to 100 percent of the design limit load. The test also featured extensive use of high-temperature fiber-optic strain sensors.*



ED10-0289-2 NASA/Tom Tschida

# Hypersonic vehicle test article

*The hypersonic vehicle test article recorded the highest temperature and most complex thermal test ever performed in the FLL. The test article was a fore-body section of a hypersonic vehicle. Maximum temperatures reached approximately 3,000 degrees F. Thermal testing required simultaneous operation of quartz lamp and graphite heating systems.*

NASA

## Global Observer wing test

*The Global Observer wing loads test featured the largest test article ever tested in the FLL. Less than half of the wingspan is represented in this image. The test article had a wingspan of 175 feet, which spanned nearly the entire FLL and was arranged diagonally to fit. It was the first loads test that utilized distributed strain sensing using optical fibers. It also was the FLL's first use of a photogrammetry system to determine wing shape during loading of a large-scale structure.*

ED14-0095-329 NASA/Ken Ulbrich

## G-III wing loads calibration

*This two-part wing loads test of a NASA G-III aircraft included a loads calibration followed by a check load test. FLL staff considers it the first ever wing loads test performed on an aircraft while being lifted off the ground on airbags.*

ED11-0166-056 NASA/Tony Landis

## Phantom Eye GVT

*The Phantom Eye is the largest aircraft the FLL staff ever subjected to a ground vibration test, or GVT. It is a high-altitude, long-endurance, highly flexible vehicle with a wingspan of 150 feet. The GVT utilized a bungee system, which suspended the aircraft from a mobile crane and ceiling structure. Although this test was not performed in the FLL, the test utilized lab equipment and instrumentation and test techniques developed in the FLL.*

ED13-0233-180 NASA/Ken Ulbrich

## HIAD torus loads testing

*FLL staff considers the Hypersonic Inflatable Aerodynamic Decelerator, or HIAD, torus test to be one of the most unique loads tests ever performed in the lab. The tests involved compression and torsion buckling of Kevlar torus, or donut shaped, test articles at various internal pressures. The HIAD inflatable entry system is designed to slow down a spacecraft entering a planetary atmosphere.*

# Heating up

## Loads lab prepping for some red-hot projects

**By Jay Levine**
X-Press editor

ED14-0033-0401 NASA/Ken Ulbrich

*Tony Chen, NASA Armstrong's HIAD testing project manager, keeps an eye on testing for NASA Langley Research Center's Hypersonic Inflatable Aerodynamic Decelerator, or HIAD, program. The HIAD testing consists of a series of donut-shaped articles that would be stacked to slow down a spacecraft entering a planetary atmosphere.*

Projects at the NASA Armstrong Flight Research Center's Flight Loads Laboratory will be hot in the future. Or at least that's the idea as the laboratory staff prepares for possible work on three separate heat shield projects for the agency.

The first of the three projects is the thermal test of the umbrella-like heat shield in support of the Adaptive Deployable Entry and Placement Technology, or ADEPT, program. This heat shield concept would deploy like an umbrella and is designed to slow down a spacecraft as it enters a planet's atmosphere.

Another heat shield project that could be coming to the FLL is the high-temperature verification test of a carbon-carbon thermal protection system for the Solar Probe Plus program, said Larry Hudson, NASA Armstrong FLL chief engineer and manager for the project.

The third project might provide an opportunity to perform the thermal test portion of a donut-shaped test article developed at NASA's Langley Research Center in Hampton, Virginia. Called the Hypersonic Inflatable Aerodynamic Decelerator, or HIAD, the test articles were at NASA Armstrong for seven months of testing at room temperature that concluded earlier this year. It could return in 2016 for some additional research.

### ADEPT

This heat shield concept differs from the other current ideas in its material and construction. Made from a 3-D, semi-rigid, woven carbon fabric, the ADEPT test article would be heated to about 2,500 degrees Fahrenheit, while simultaneously applying mechanical loads, Hudson explained.

Test articles could come to NASA Armstrong later this year, with increasingly complicated and larger test articles arriving through 2018, he said.

"The challenge for us from 2015-18 is to integrate two big tests at the same time using the same resources and test systems," Hudson said.

As part of NASA's Space Technology Game Changing Development Rapid Technology Infusion, ADEPT could allow mission planners to develop an aeroshell design that fits within existing launch vehicle systems. When it deploys from the aeroshell, it is expected to significantly reduce heating, acceleration and pressure of the spacecraft as it enters the atmosphere. If successful, ADEPT would be used to deploy scientific payloads or enable long-term exploration cargo needs to other planets.

### Solar Probe Plus

The FLL is proposing to conduct the Solar Probe Plus research, which would heat large carbon-carbon thermal protection system panels from room temperature to 2,500 degrees F, Hudson explained. Two panels of slightly different sizes will be tested and have a hexagonal shape with rounded corners.

One of the first challenges is designing the heating system to bake the approximately 90-inch by 90-inch by four-inch-thick panels. The radiant heating system will consist of both quartz-lamp and graphite element heaters.

"The first test that we will perform is a checkout test of a small test specimen that is about the size of a brick. Once we have developed the instrumentation and test techniques from this test, we will then apply that knowledge to instrumenting and testing the first of the two large panels. Any additional knowledge gained from the first large panel test will be incorporated into testing the second large panel. All of the test articles will be instrumented with thermocouples, optical temperature sensors and high-temperature fiber-optic strain sensors," Hudson said.

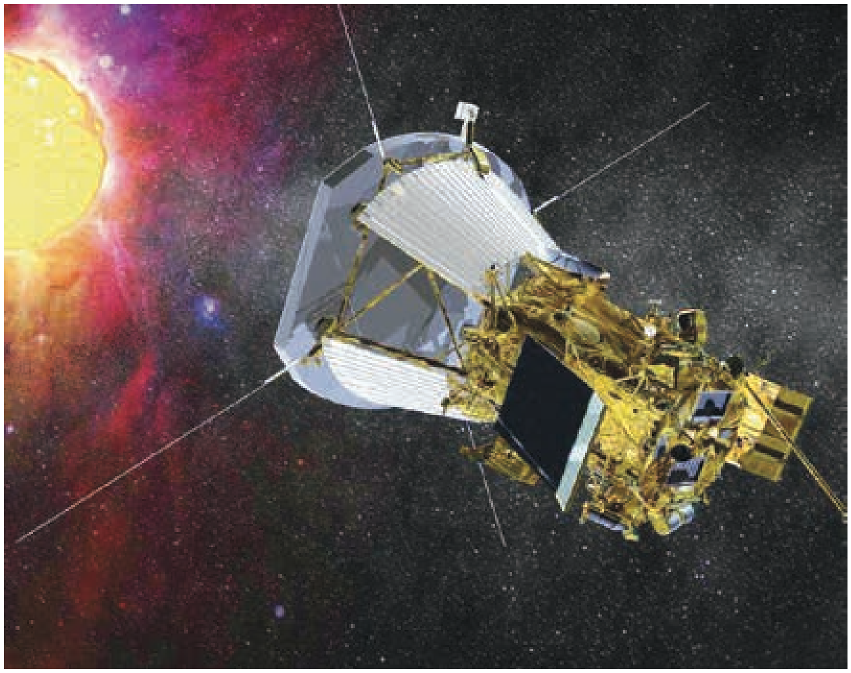
The first small test item is anticipated to arrive in early 2015 followed by the first large panel in the summer of 2015. The second of the large panels will arrive in late 2015.

Research on the panels for the Solar Probe will require massive amounts of power for the test that will need to be conducted at 2,500 degrees F, Hudson said.

"It will be one of the largest high temperature test articles we've ever tested and will most likely require the most power we have ever needed for a heating test," Hudson said. "The biggest challenge will be to effectively heat the test article for an hour-long test at 2,500 degrees F."

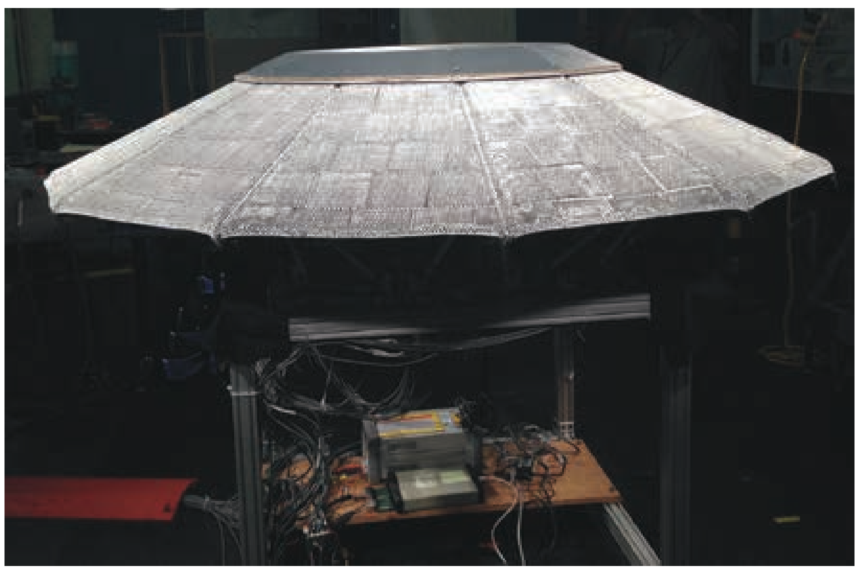
Solar Probe Plus will repeatedly sample the near-sun environment, revolutionizing current knowledge and understanding of coronal heating and of the origin and evolution of the solar wind and answering critical questions in heliophysics that scientists have ranked as top priorities for decades.

By making direct, in-situ measurements of the region where some of the most hazardous solar energetic particles are energized, Solar Probe Plus will make key contributions to researchers' ability to characterize and forecast the composition of the radiation environment in which future space explorers will work and live.



NASA

*A planned future heat shield project for the FLL is the high-temperature verification test of a carbon-carbon thermal protection system for the Solar Probe Plus program.*



NASA

*The FLL is planning tests in support of a heat shield for the Adaptive Deployable Entry and Placement Technology, or ADEPT, program heat shield. This heat shield concept would deploy like an umbrella and is designed to slow down a spacecraft as it enters a planet's atmosphere.*

**HIAD**

The inflatable system, consisting of a series of stacked donut-shaped rings of different diameters, is designed to more efficiently slow down a spacecraft, while entering a planet's atmosphere. This type of entry system could be more economical than traditional methods and be available for use on a Mars rover-size craft beginning in about 2020.

Prior to the hardware's full development, it had to undergo tests of its structural performance under various types of loading conditions. NASA Armstrong worked on the eight different donut-shaped test articles that came in three different sizes. The test articles had previously been tested under simulated flight loads, but the additional testing helped validate models for future decelerator configurations.

NASA Armstrong innovation also was tapped. Loads lab researchers had been looking at new strain gauges and the HIAD presented the perfect opportunity to develop those devices, said instrumentation specialist Anthony "Nino" Piazza. Strain gauges used for the HIAD tests were constructed from highly elastic tubes, used frequently in the medical field for sensitive arterial procedures that require monitoring changes in volume.

The testing involved the flexible sensors and hydraulic jacks that applied mechanical loads to each test article, said Tony Chen, NASA Armstrong's HIAD testing project manager. The sizes tested had diameters of roughly 11, 13 and 15 feet, about half the size envisioned for the functional system that would use about eight to 10 concentric rings.

A series of straps on the top and bottom of the test articles applied mechanical loads to cause the donuts to be pulled inward or twisted to determine their structural characteristics, Chen explained. Each test article was built differently in order to find the optimal design for their construction. The test articles were also tested at various inflation pressures to see the differences in their structural integrity.

In an actual spacecraft, a connected stack of donut-shaped rings would be inflated before entering a planet's atmosphere to slow the vehicle for landing. The spaceship would look a lot like a giant cone with the space donuts assembled, similar to a child's stacking ring toy. The stacked-cone concept would allow NASA to land heavier payloads than is currently possible on the surface of the planet and could eventually be used to deliver crews. The project was funded through a NASA Game-Changing Technology program.

Whatever new developments arise in heat shield technology, FLL leaders are ready to assist.

# Staying power

## FLL culture, longevity lead to success

**By Jay Levine**
X-Press editor

The NASA Armstrong Flight Research Center's Flight Loads Laboratory continues to thrive after five decades because it provides a mix of valuable capabilities; dynamic thinking to meet challenges and a culture of mentoring that reinforces its mantra of getting the work done.

"We have been adding to the understanding of the thermal and structural performance of flight vehicles and structures in the flight loads lab from its beginning," said Larry Hudson, FLL chief test engineer. "We deliver high quality data that satisfies the customers' needs with a goal to deliver it on time and on budget by doing it right the first time."

Bill Lokos, a center aerospace engineer for nearly four decades, explained why structural testing is critical.

"Flight research has a hand-in-hand relationship with ground testing and ground research," Lokos said. "Before a highly modified research aircraft can fly, you have to be able to establish confidence that it can accomplish the mission safely. For safety of flight of a highly modified airplane, or a brand new airplane, there are two things you use to verify that. One is analysis and the other is ground testing. You can't do elaborate, extensive high-performance flight research without doing high-performance ground (loads) testing."

Natalie Spivey, a structural dynamics engineer, discussed why the lab does some of what it does.

"We often fly one-of-kind test articles and prior to flight we need to demonstrate the test article is worthy of conducting flights in a safe manner for the mission," Spivey said. "One area needed for airworthiness clearance is to verify the structure's aeroelastic instabilities, such as flutter, and that there is sufficient margin to satisfy the project's requirements. Sufficient flutter margin is validated through dynamic analysis and testing."

ED13-0126-1 NASA/Ken Ulbrich

*Principal investigator Bill Lokos, left, and test conductor Larry Hudson review the test checklist prior to initiating the airbag lift of the G-III aircraft.*

ED13-0233-159 NASA/Ken Ulbrich

*From left, Michael Lindell, Anthony "Nino" Piazza, Matthew Moholt and Tony Chen monitor a HIAD test.*

A finite element model, or FEM, is developed for use in the flutter analysis and validated with results from performing ground vibration tests, or GVTs, she explained.

"The FLL has an impressive suite of hardware, software and the knowledge required for small and large scale GVTs," Spivey said. "Mass property testing provides measured mass properties – such as mass, center of gravity and moments and products of inertia – for the FEM development which goes into the flutter analysis. The FLL ground testing assets and knowledge play a large role in providing structural dynamics flight clearance for AFRC projects in order to advance technology."

NASA Armstrong researcher Marty Brenner expanded Spivey's explanation.

"Structural modes interaction, or SMI, testing is necessary when there are concerns with the interaction of the flight control laws and the aircraft structure," Brenner said. "The SMI testing validates an aeroservoelastic analysis, which couples the structural dynamics, unsteady aerodynamics, control surfaces, sensors and digital feedback control laws."

In order to collect the data for models and validation, instrumentation is key. Anthony "Nino" Piazza, NASA Armstrong instrumentation specialist, explained how instrumentation is a unique FLL feature.

"We have the capability to instrument items ranging from liquid cryogen to near reentry temperatures for both electrical and fiber optic sensor needs. We also have an expertise in attaching to uncommon materials like ceramic composites and other super alloys. Over the years thermal spray attachment techniques have been developed and are continually adapting to the need to adhere with new material systems for higher temperature applications."

Craig Stephens, NASA Armstrong's Adaptive Compliant Trailing Edge project chief engineer, said the loads lab is similar in culture to a family, where people come together, ideas are openly shared and they help each other to improve the projects they are working.

"It's interesting work (in the FLL) where we are continually trying to push the envelope of structural test capabilities," Stephens said. "We have a reputation from our past work with external airframe companies. They know they can come here for some pretty difficult testing requirements and know they will get the test data they are looking for. We are one of only two government facilities in the country that can conduct large-scale combined thermal and mechanical testing. Combined with our skilled workforce and successful completion of past tests is one reason for the lab's longevity."

Tom Horn, who spent nearly a decade as the Aerostructures Branch chief, said the anniversary is a time for reflection.

"To celebrate the past accomplishments is fine, but we need to really take a look back at how the work in the lab has evolved, how what is being asked of us has evolved and keep an eye toward the future and how that evolution will continue. It's not just about looking back and saying, 'Hurrah what a great job,' but it is drawing lessons from that look back. Now let us keep going forward for the next 50 or more years."

Horn said the FLL's ability to test the untestable is a key reason for its longevity: "The people in the lab know how to make that stuff happen and come up with some really innovative solutions. They have the ability to sit back and think about it. Some of the sensor solutions have been that way. They always want to do something new and have a willingness to look at new ways of doing things."

The FLL staff also is self-motivated.

"One of our motivations is knowing that we are really trying to do something that nobody else has been able to do before. Providing the best information possible and the best quality test for the customer to get their answers. We worry about the little things like boundary conditions, what angles loads are being applied at. If you don't do it right and leave a lot of uncertainties and questions in your test data, then it can't solve your problem. We have that desire to get it right," Horn said.

Lokos also offered insight into the lab's longevity.

"Multiple generations of people have worked here and I have overlapped with a number of them. There is a history of technical challenges that the loads lab has met over the years for the different flying projects," Lokos said. "Research efforts have included access to space such as the space shuttle system, high-speed flight like YF-12, low-speed, high-altitude, long-endurance projects like the Global Observer testing and hypersonics. It is a body of work over a long period of time that illustrates the different challenges investigated by the aerospace community and the loads lab has been a part of that."

As a package, the NASA Armstrong Flight Loads Laboratory facilities are tough to match.

"The combination of experiences we have here is rare," Lokos explained. "We have thermal high temperature capability that over the years has been maintained. The load testing capability has doubled – we used to have 40 channels of load control and we now have 80. We have the ability to merge both of those with temperature testing and load testing at the same time."

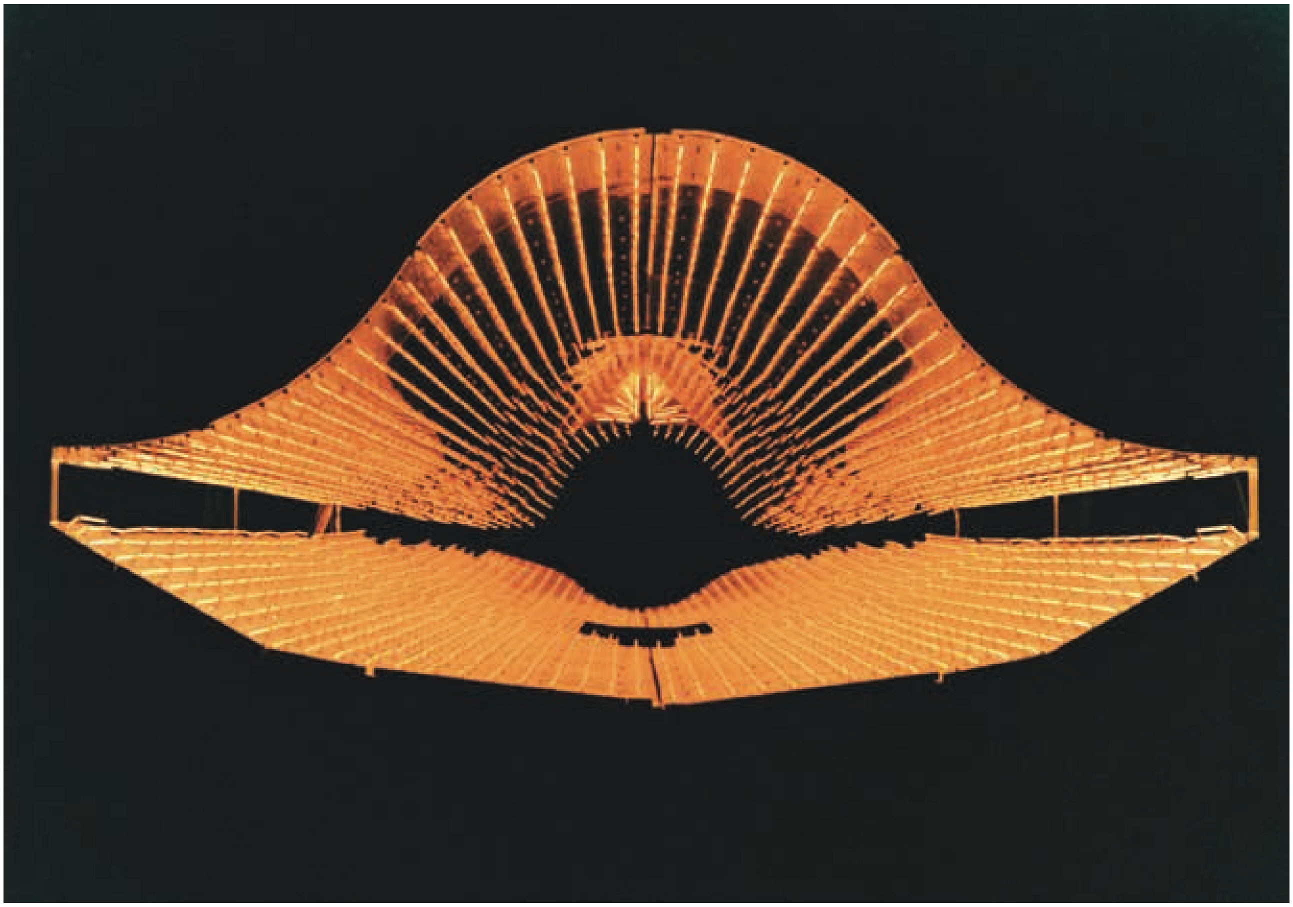
Whatever the challenges that face the FLL next, one thing is clear – lab personnel will be ready to meet them.

EC99-44959-7 NASA/Tony Landis

*Tom Horn prepares a shot bag loads test of a flight test fixture. Horn later served as Aerostructures Branch chief for nearly a decade.*

EC80-14327 NASA

*Roger Fields, from left, shows Mike DeAngelis and Dr. William Ko a feature of this test panel setup.*



E71-2789 NASA

*The YF-12 forebody radiant heating system testing is captured in this classic image from 1971.*

NASA

*Anthony "Nino" Piazza applies thermal spray in preparation for high-temperature instrumentation.*

ED14-0033-029 NASA/Ken Ulbrich

*Ray Sadler sets up a photogrammetry system for a Hypersonic Inflatable Aerodynamic Decelerator, or HIAD, test article.*

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